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Minerals, Scientific and Medical Books.

A. E. FOOTE, M.D., 4116 Elm Ave., Philadelphia, Pa., U. S. A.

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Professor Foote personally collected some remarkable meteorites, at Cañon Diablo, Arizona. The largest mass weighs 201 lbs., and another 154 lbs.

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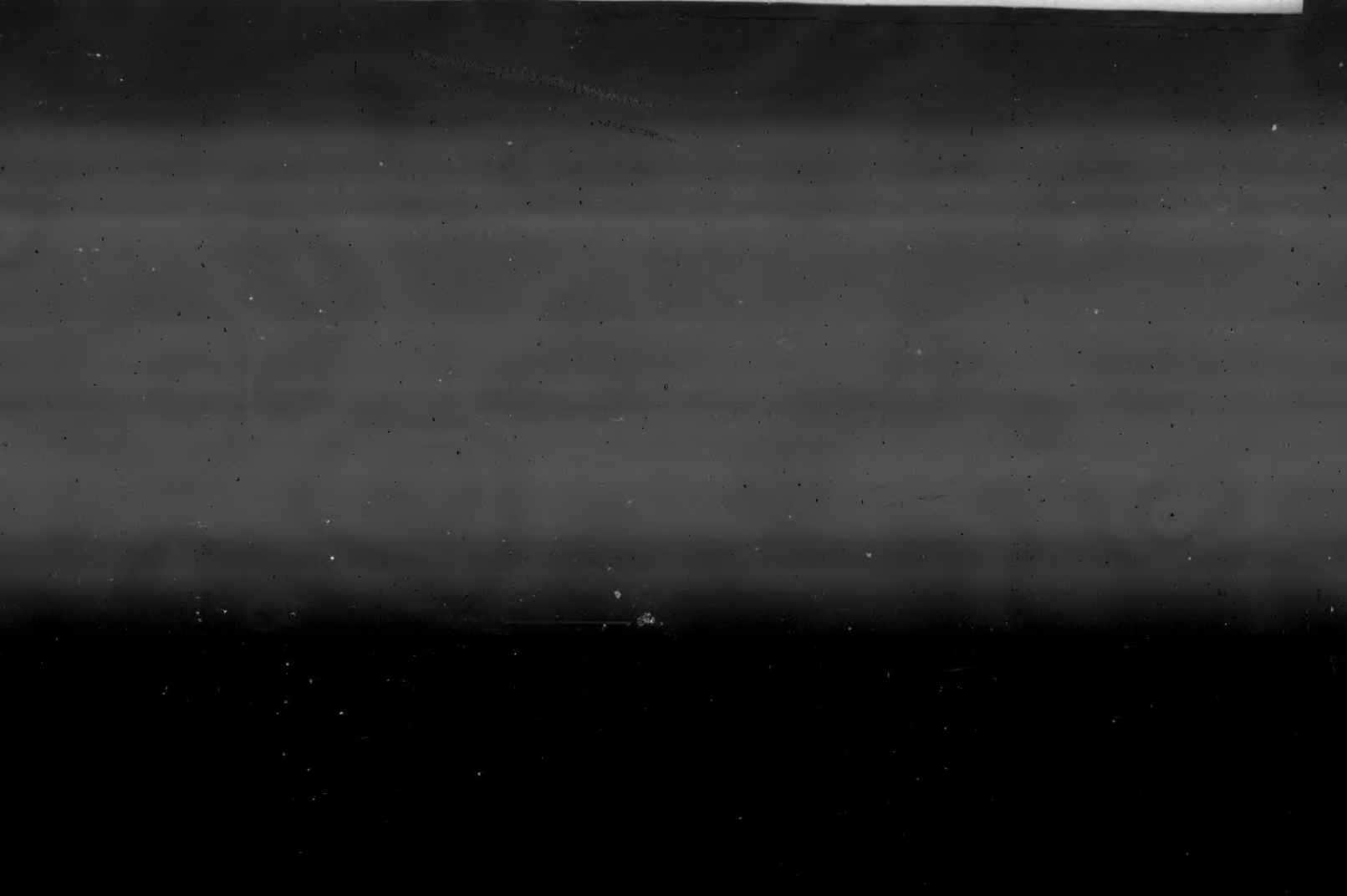


THE

AMERICAN JOURNAL OF SCIENCE

[THIRD SERIES.]

ART. XVII.—*On the Capture of Comets by Planets, especially their Capture by Jupiter;* by H. A. NEWTON.

1. SOME years ago I obtained and published* a formula expressing in simple terms the total result of the action of a planet in increasing or diminishing the velocity of a comet or small body that passes near the planet. This formula is practically a modification of the integral of energy, the smaller terms in the perturbing function being omitted. A very brief and partial treatment of it was presented to the British Association for the Advancement of Science in 1879 at its Sheffield meeting.† Within the last two or three years several astronomers have made special study of the manner of Jupiter's action in changing the orbits of comets that pass very near him. M. Tisserand has given us an expression connecting the major axis, inclination and parameter of the orbit described before coming near to Jupiter with the corresponding elements of the orbit after leaving the neighborhood of the planet.‡ M. Schulhof has applied the formula of M. Tisserand as a criterion for determining the possible identity of various comets whose orbits pass near to Jupiter's orbit.§ Messrs. Seeliger, Callandreau and others have continued these investigations. The interest thus shown in the problem has led me to resume the study of the subject, and to work out the results of the formula obtained by me in 1878 more fully than they have been hitherto developed.

* This Journal, III, vol. xvi, p. 175, 1878.

† Report, 1879, p. 274.

‡ Sur la théorie de la capture des comètes périodiques, Bull. Astron., Tome vi, juin and juillet, 1889.

§ Notes sur quelques Comètes a courte période, Astron. Nachrichten, No. 2964.

2. One of the remarkable distinctions between the comets of long (or infinite) periods, and those of short periods, is that the orbits of the latter have almost without exception direct motions and small inclinations to the plane of the ecliptic, while the orbits of the former have all possible inclinations between 0° and 180°. At first sight this seems to imply that the two groups of comets are radically distinct in origin or nature one from the other. The most natural line of investigation therefore is the effect of perturbations in bringing or not bringing the comets to move with the planet after the perturbation.

3. The algebraic processes by which was obtained the formula for the change of energy which a small body experiences from passing near a planet were given in the article cited, and they need not be here reproduced. The following was the resulting equation, viz:

$$\Delta = -\frac{4mfa^2v_1 \cos\varphi \sin\alpha}{pv_0}, \qquad (1)$$

and it was obtained from the general differential equations of motion by making assumptions not greatly differing from those used in obtaining Laplace's well known theorem, that a sphere of suitable magnitude may be described about the planet as a center and that for a tolerable first approximation the comet may be regarded as moving when without this sphere in a conic section of which the sun is the focus, and as moving when within the sphere in a conic section (an hyperbola) of which the planet is the focus. In other words, only perturbations of the first order of magnitude are taken account of. A comet is treated throughout this paper as a small indivisible body whose mass may be neglected.

4. *Notation.* The symbols used in (1) and also other symbols which I shall have occasion to use may be thus defined.

Let $\mathfrak{C}_1$ be the orbit of the comet about the sun before the comet comes under the appreciable action of the planet;
$\mathfrak{C}$ the orbit of the comet about the sun after perturbation by the planet;
C the hyperbolic orbit of the comet relative to Jupiter when near the planet;
$\mathfrak{J}$ the elliptic orbit of Jupiter about the sun;
A the point on $\mathfrak{C}_1$ which is nearest to $\mathfrak{J}$;
E the point on $\mathfrak{J}$ which is nearest to $\mathfrak{C}_1$;
d the length of the straight line EA being the perpendicular distance between the orbits at their nearest approach;
ω the angle between the tangent of $\mathfrak{C}_1$ at A and the tangent to $\mathfrak{J}$ at E;

Let h be the distance which the planet has yet to pass over to reach E when the comet is at A (h may be negative);

m the mass of the planet, sun's mass=unity;

a the unit of distance, in general the mean distance of the earth from the sun;

f the sun's attractive force at the unit of distance;

v_1 the planet's velocity in its orbit at E;

v_0 the comet's velocity in its orbit C when the comet enters the sphere of Jupiter's perceptible influence;

v the comet's velocity at A relative to the sun;

s $=v_0/v_1$;

$@_1$ the semi-axis major of $\mathfrak{C}_1$ (negative if $\mathfrak{C}_1$ is an hyperbola);

$@$ the semi-axis major of $\mathfrak{C}$ (negative if $\mathfrak{C}$ is an hyperbola);

p the perpendicular from the planet upon asymptote to C;

α the acute angle between the transverse axis of C and the asymptote to C.

φ the angle between the tangent to $\mathfrak{J}$ at O (drawn in the direction of the planet's motion) and the line from the planet to the vertices and center of C;

A the semi-transverse axis of C;

B the semi-conjugate axis of C (hence equal to p);

r the distance of the planet from the sun;

r_1 the distance of the comet from the sun;

r_0 the distance of the comet from the planet;

ρ_1 and ρ distances of the comet from the sun at selected epochs before and after perturbation;

u_1 and u the velocities of the comet at the selected epochs;

Δ the increase to which $v^2-\frac{2fa^2}{r_1}-\frac{2mfa^2}{r_0}$ receives by the planet's action during the whole period in which the comet is passing near to Jupiter.

5. If we assume two epochs, one before and one after the perturbation, at which the comet is equally distant from the planet, the term $2mfa^2/r_0$ is the same at both instants, and it disappears from the value of Δ. Therefore

$$\Delta = u^2 - \frac{2fa^2}{\rho} - u_1^2 + \frac{2fa^2}{\rho_1}.$$

But by the well-known formulas from the law of gravitation,

$$u_1^2 = 2fa^2\left(\frac{1}{\rho_1} - \frac{1}{2@_1}\right),$$

and

$$u^2 = 2fa^2\left(\frac{1}{\rho} - \frac{1}{2@}\right);$$

hence

$$\Delta = fa^2\left(\frac{1}{@_1} - \frac{1}{@}\right),$$

that is, from (1)

$$\frac{1}{@_1} - \frac{1}{@} = -\frac{4m\cos\varphi\sin\alpha}{ps}.$$

This equation is valid whatever be @, the major axis of the orbit $\mathfrak{C}$, and may be used to determine the major axis of either orbit from the elements of the other. My present purpose is, however, to study the action of Jupiter in changing orbits that are originally parabolas, and hence in general @, will be taken infinite. In that case

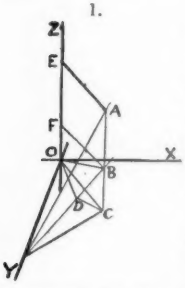
$$@ = \frac{ps}{4m \cos \varphi \sin \alpha}. \qquad (2)$$

It will be found that the second number of (2) depends on ω, d and h, and these are known quantities when the elements of $\mathfrak{C}$, and $\mathfrak{J}$ are given. The use of the equation is moreover greatly simplified and enhanced by the fact that the plane of the planet's orbit is involved only in so far as that it must contain the tangent to $\mathfrak{J}$ at E.

6. In the second member of (2) all the factors are positive except cos φ, hence, if $\varphi < \frac{1}{2}\pi$, @ is positive and the orbit $\mathfrak{C}$ is an ellipse; but, if $\varphi > \frac{1}{2}\pi$, @ is negative and $\mathfrak{C}$ is an hyperbola. This result may be thus expressed; *if the comet passes in front of Jupiter the kinetic energy of the comet is diminished, if it passes behind the planet the kinetic energy of the comet is increased.* The reason for this may also be given in general language. If the comet passes in front of the planet the comet's attraction increases the velocity, and hence increases the kinetic energy of the planet and *vice versa*. But the total energy of the two bodies is constant; so that when that of the planet is increased, that of the comet is diminished and *vice versa*.

7. It is desirable now to transform the value of @ given in equation (2) so as to be able to determine the major axis of the new orbit of the comet directly from the circumstances of its initial approach to the planet before perturbation; in other words, to find @ in terms of ω, d and h. For this we must find in terms of ω, d and h, values for s, p, a and φ.

1.



8. *To find s.*—In fig. 1 let A and E represent the two points A and E as defined above (Art. 4), and the line AE represent d. Let AY be the tangent to $\mathfrak{C}$, at A, and EO the tangent to $\mathfrak{J}$ at E. It is an admissible supposition that the planet is describing the *straight* line OE, and that the comet in its unperturbed orbit is describing the *straight* line YA. At some certain moment the line joining the planet and the unperturbed comet must evidently be perpendicular to OE. Let OY be the line joining the bodies at that moment, so that the planet is at O when the comet is at Y, and EOY is a right angle. Instead, however, of supposing the

planet to move from O towards E we may apply an equal, opposite motion to the comet, and consider the planet to remain at rest at O. Draw AC parallel to EO and make AB equal to the distance described by the planet during the time that the comet is moving from Y to A. Join YB. Then since YA and BA represent in direction and magnitude the motions of the two bodies in a given interval, the third side YB of the triangle represents in magnitude and direction the motion of the comet relative to the planet. The angle YAB is the angle ω, and the three sides of the triangle YA, YB and BA are proportional to v, $v_\circ$ and $v_\prime$. Let the angle YBC be θ; then from the triangle YAB we have

$$v_\circ^2 = v_\prime^2 - 2v_\prime v \cos\omega + v^2,$$

and

$$v : v_\prime : v_\circ :: \sin\theta : \sin(\theta-\omega) : \sin\omega. \qquad (3)$$

Since v and $v_\prime$ can be computed from the given elements of the orbits of the planet and comet, we may readily compute from ω the value of s, or $v_\circ/v_\prime$. But if the planet is at its mean distance from the sun, and the comet's orbit is parabolic, $v^2 = 2v_\prime^2$, and we have

$$s^2 = 3 - 2\sqrt{2}\cos\omega. \qquad (4)$$

Also from the triangle

$$2v_\prime^2 = v_\circ^2 + 2v_\circ v_\prime \cos\theta + v_\prime^2,$$

or

$$2s\cos\theta = 1 - s^2. \qquad (5)$$

9. *To find p.*—The planet being regarded at rest at O and the *relative* unperturbed motion of the comet being along YB, this line may within admissible limits of error be treated as one asymptote of the relative orbit C. The perpendicular from O upon YB will then be by definition (Art. 4) the line p. Draw OX from O perpendicular to OY and OE, and let these three lines be coördinate axes. Let the line AB meet the plane XOY in C. Join OC, let fall OD perpendicular to YB, and join CD. Since EA is perpendicular to AY and also to EO, and so to its parallel line AC, therefore it is perpendicular to the plane YAC. Hence OC, parallel to EA is perpendicular to the plane, and so perpendicular to CD. Again CDY is a right angle; for $OD^2+DY^2=OY^2=OC^2+CY^2$, and $OD^2=OC^2+DC^2$. Hence $DC^2+DY^2=CY^2$, and consequently CDY is a right angle.

The quantity h is the line BC; for h is the distance which the planet, when the comet is at A, has yet to pass over before reaching E. But the comet was at Y when the planet was at O, and the planet describes BA, while the comet describes YA, leaving BC as the distance yet to be described or h. But the angle CBD is θ, so that we have

$$p^2 = OD^2 = OC^2 + CD^2 = d^2 + h^2\sin^2\theta. \qquad (6)$$

10. *To find* α.—The angle α is the acute angle between the asymptote and the transverse axis of the hyperbola, and hence from the nature of the hyperbola $\tan \alpha = B/A$. By known formulas we have, if the planet is at its mean distance

$$v_1^2 = 2fa^2\left(\frac{1}{r} - \frac{1}{2r}\right),$$

$$v_\infty^2 = 2mfa^2\left(\frac{1}{\alpha} + \frac{1}{2A}\right).$$

Therefore $$\frac{v_\infty^2}{v_1^2} = \frac{mr}{A}, \text{ or } A = \frac{mr}{s^2}.$$

Hence from (6) $$\tan \alpha = \frac{B}{A} = \frac{p}{A} = \frac{s^2(d^2 + h^2 \sin^2 \theta)}{mr}. \qquad (7)$$

11. *To find* φ.—The orbit of the comet relative to Jupiter lies in the plane YOB. Let i be the inclination of the plane YOB to YOX, measured positive from x positive to z positive; let l be the longitude of the direction YC, measured in the plane YOX from OY, that is, the angle made by YC with OY produced; let λ be the longitude of the direction YB measured in the plane YOB from OY, that is, the angle made by YB with OY produced. Imagine now a sphere described about Y as a center that shall cut the three planes XOY, BOY and BCY in three sides of a right angled spherical triangle. The hypotenuse of this triangle is λ, the base l, the perpendicular $\frac{1}{2}\pi - \theta$, and the angle opposite to the perpendicular is i; hence we have

$$\cos \lambda = \cos l \sin \theta, \qquad (8)$$

$$\cos \theta = \sin i \sin \lambda, \qquad (9)$$

$$\cot i = \sin l \tan \theta. \qquad (10)$$

Also from the triangles OCY and BCY

$$\tan l = \tan \text{OYC} = -\frac{\text{OC}}{\text{YC}} = -\frac{d}{h \tan \theta}. \qquad (11)$$

The angle φ is by definition the angle between the direction OE, and a line in the plane YOB that makes with YB an angle α. Hence we have readily

$$\cos \varphi = \sin i \sin (\lambda \pm \alpha). \qquad (12)$$

These equations enable us to compute φ in terms of d, h and ω; for in succession θ may be computed by (3), l by (11), λ by (8), i by (10), and φ by (12).

12. These values of s, p, α and φ give by equation (2) the value of @. The suppositions that the planet is at its mean distance, and that $\mathfrak{C}_1$ is a parabola, are involved in that equation, but they are not necessary to the determination of @ when no such hypotheses are made, and changes in the equation

that are not serious would make it applicable without these limitations. The quantities in the several equations may be regarded as having values:—

d positive,
h positive or negative,
α positive and less than $\frac{1}{2}\pi$,
ω, θ, φ and i positive and less than π,
l and λ positive and less than 2π.

13. We may, however, also find directly the value of @ in terms of d, h, and the known functions of ω.

From (12)

$$\cos\varphi \sin\alpha = \sin i \sin\lambda \cos\alpha \sin\alpha \pm \sin i \cos\lambda \sin^2\alpha.$$

From (7)

$$\cos\alpha \sin\alpha = \frac{AB}{A^2+B^2}, \text{ and } \sin^2\alpha = \frac{B^2}{A^2+B^2}.$$

From (10) and (8)

$$\sin i \cos\lambda = \pm \frac{\cos l \sin\theta}{(1+\sin^2 l \tan^2\theta)^{\frac{1}{2}}} = \pm \frac{\cot l \sin\theta}{(\sec^2\theta+\cot^2 l)^{\frac{1}{2}}},$$

hence from (6) and (11)

$$\sin i \cos\lambda = \pm \frac{h \sin^2\theta}{(d^2+h^2\sin^2\theta)^{\frac{1}{2}}} = \pm \frac{h \sin^2\theta}{B}.$$

From these and (9)

$$\cos\varphi \sin\alpha (A^2 + B^2) = AB \cos\theta \pm hB \sin^2\theta,$$

and hence from (2)

$$@ = \frac{s}{4m} \cdot \frac{A^2+B^2}{A\cos\theta \pm h\sin^2\theta} = \frac{s}{4m} \cdot \frac{A^2+d^2+h^2\sin^2\theta}{A\cos\theta \pm h\sin^2\theta} \quad (13)$$

Since m is the known mass of the planet, and θ, s and A are known functions of ω, equation (13) gives directly the value of @, the semi-axis major of the new orbit $\mathfrak{C}$ in terms of d, h and ω.

14. For a particular case of approach, equation (13) is convenient for computation. We may, however, now treat d, h and ω as independent variables whose varying values may express all the different possible cases of approach of the comet to the planet so far as change of periodic time of the comet is concerned. The dependence of @ upon the *three* variables cannot be very easily represented graphically in a single plane diagram. But by giving to ω successive values in multiples of 10°, viz: ω=10°, 20°, 30°, etc., to 170°, I have prepared a series of diagrams to exhibit in each case in succession the relation of @ to the other two variables. The values of θ, s and A for the several values of ω were needed in making the diagrams and they are given in Table I. Equations (4), (5)

and (7) are used in making the table. The disturbing planet is assumed to be Jupiter, so that m was taken equal to 1/1050 and $r=5{\cdot}2$.

TABLE I.

ω	θ	s	A	ω	θ	s	A
0°	0° 0′	0·414	·02886	100°	131° 48′	1·868	·00142
10	32 1	0·463	·02309	110	138 9	1·992	·00125
20	55 47	0·585	·01448	120	144 21	2·101	·00112
30	72 22	0·742	·00900	130	150 26	2·195	·00103
40	84 46	0·913	·00594	140	156 26	2·273	·00096
50	94 47	1·087	·00419	150	162 22	2·334	·00091
60	103 27	1·259	·00312	160	168 16	2·379	·00088
70	111 14	1·426	·00244	170	174 8	2·405	·00086
80	118 27	1·584	·00197	180	180 0	2·414	·00085
90	125 16	1·732	·00165				

15. Using these values of θ, s and A we may now represent graphically the dependence of @ upon the other two variables d and h for each specified value of ω. Let d and h be Cartesian coördinates, then for each point of the coördinate plane there is a value of @ The ambiguous sign will be fully satisfied by giving positive and negative values to h. For an assumed value of @ we shall have a curve whose equation is (13), and each point of this curve represents values of d and h for which the total action of the planet upon the comet will be to reduce the energy of the comet a constant amount. This locus will be called an *isergonal* curve.

16. *Faisceau of isergonal ellipses.*—The equation (13) of the isergonal curve may be written

$$4m@\ (\mathrm{A}\cos\theta+h\sin^2\theta)=s(\mathrm{A}^2+d^2+h^2\sin^2\theta),$$

and this is the equation of an ellipse. As @ changes its value we may treat it as a parameter and we have a faisceau of similar isergonal ellipses, each ellipse symmetrical with the axis of h. The radical axis of the faisceau $\mathrm{A}\cos\theta+h\sin^2\theta=0$, and the imaginary ellipse $\mathrm{A}^2+d^2+h^2\sin^2\theta=0$, are theoretically two members of the faisceau. For points on the radical axis $@=\infty$ and therefore for this locus there is no change in the energy of the comet.

17. *Center and area of the isergonal ellipse.*—The center of the isergonal ellipse is upon the axis of h; making $d=0$, and solving for h we have

$$h=\frac{2m@}{s}\pm\frac{2m@}{s\sin\theta}\left(1-\left(\cos\theta-\frac{\mathrm{A}s}{2m@}\right)^2\right)^{\frac{1}{2}}. \qquad (14)$$

The first term of the second member of (14) is the ordinate of the center, and the second term is the semi-axis major of the

ellipse. The ratio of the axes being $1 : \sin\theta$, and As^2 being $=mr$, the area of the ellipse will be equal to

$$\frac{4\pi m^2 @^2}{s^2 \sin\theta}\left(1-\left(\cos\theta-\frac{r}{2as}\right)^2\right).$$

18. *Maximum action of the planet.*—For two particular values of @ the isergonal ellipses become points. These values of @ result if the maximum effect of the planet in increasing and in decreasing the energy of the comet takes place, and they are obtained by making the two values of h equal to each other in (14), that is, by making $\cos\theta-\frac{As}{2m@}=\pm 1$. Since at the same time $h=2m@/s$, we obtain

$$h=\frac{A}{\cos\theta\pm 1}, \quad \text{and} \quad @=\frac{As}{2m(\cos\theta\pm 1)}. \qquad (15)$$

Let h' and h'', and $@'$ and $@''$ be the positive and negative values of h and @ in (15) and we may construct the following table of their values. As in Table I Jupiter is assumed to be the perturbing planet.

TABLE II.

ω	h'	h''	$@'$	$@''$	ω	h'	h''	$@'$	$@''$
0°	·01443	α	3·14	$-\alpha$	100°	·00426	−·00085	4·17	−0·83
10	·01250	−·15174	3·04	−36·90	110	·00489	−·00072	5·12	−0·75
20	·00927	−·03307	2·85	−10·15	120	·00598	−·00062	6·60	−0·68
30	·00690	−·01290	2·69	− 5·03	130	·00789	−·00055	9·09	−0·63
40	·00544	−·00654	2·61	− 3·13	140	·01149	−·00050	13·71	−0·60
50	·00457	−·00387	2·61	− 2·21	150	·01934	−·00047	23·70	−0·57
60	·00407	−·00253	2·69	− 1·68	160	·04192	−·00044	52·36	−0·55
70	·00382	−·00179	2·86	− 1·34	170	·16336	−·00043	206·30	−0·54
80	·00377	−·00134	3·14	− 1·11	180	α	−·00043	α	−0·54
90	·00390	−·00105	3·55	− 0·95					

19. *Explanation of Table II.*—The meaning of the numbers in this table may be explained by an example. If a comet moving in a parabola passes near to Jupiter, and the directions of the two original motions at nearest points of the orbits make an angle of 10°, then the greatest action of Jupiter (during the whole period of transit) in diminishing the velocity of the comet in its orbit about the sun will take place if the two orbits actually intersect ($d=0$), and if the comet in its unperturbed orbit arrives first at the point of intersection at the instant when Jupiter is distant therefrom ·01250 (the earth's mean distance from the sun being unity). The resulting semi-axis major of the comet's orbit about the sun will be 3·04.

On the other hand, the greatest effect in increasing the velocity of the comet will take place when the two orbits

actually intersect, and the comet in its unperturbed orbit reaches the point of intersection later than the planet and when the planet is distant therefrom 0·15174. The semi-transverse axis of the resulting hyperbolic orbit about the sun will be 36·90.

20. *Resulting orbits of maximum perturbation.*—The position of the relative orbit about Jupiter in these cases of maximum perturbation for given values of ω is easily determined. From the equations (7), (6) and (15)

$$\tan \alpha = B/A = h \sin\theta/A = \sin\theta/(\cos\theta \pm 1).$$

The positive sign gives $2\alpha = \theta$, and the negative sign gives $2\alpha = \pi + \theta$. But the angle 2α in the first case is the angle of the asymptotes enclosing the branch of the hyperbola described about Jupiter by the comet. Since the two original orbits intersect, the plane of the relative orbit contains the planet's path, so that the comet passes directly in front of the planet and being turned backward leaves Jupiter exactly in the direction of Jupiter's quit.* The place of encounter with Jupiter will be near an apse of the comet's resulting orbit about the sun. The comet leaves the planet with the relative velocity v_0, so that if $s<1$ the motion about the sun in the new orbit will be direct; if $s>1$ the motion in the new orbit will be retrograde. That is, by (4) when $\omega < \frac{1}{4}\pi$ the resulting motion is direct; when $\omega > \frac{1}{4}\pi$ the resulting motion is retrograde.

In the second case the angle 2α, being greater than 180°, stands for the angle between the asymptotes exterior to the orbit. Hence the comet passing behind the planet will be turned forward and will leave the planet in the direction of Jupiter's goal, and have a velocity that will send it permanently out of the solar system.

21. The results of Art. 20 assume that ω is given. To find for what value of ω the period of the resulting orbit is the shortest possible we may put $As^2 = mr$ and $1 - s^2 = 2s\cos\theta$ in (15) so that

$$@ = \frac{r}{1 - s^2 \pm 2s}.$$

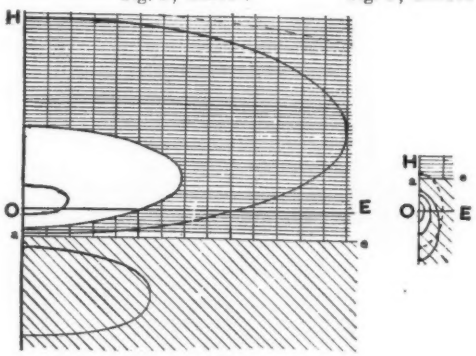
To find the minimum for @ place $\frac{d@}{ds} = 0$ in this equation. This gives $s = \pm 1$, in which result since s is inherently positive only the positive sign is used. But when $s=1$, $@ = \frac{1}{2}r$, $h = mr$ and $\omega = \frac{1}{4}\pi$. *Hence the greatest effect of perturbation of a planet moving in a circular orbit in shortening the periodic time of a comet originally moving in a parabola is obtained if the comet's original orbit actually intersects the planet's orbit at an angle of* 45°, *and if the comet is due first at the*

* The *goal* and the *quit* of a moving body are those two points on the celestial sphere *towards* which and *from* which the body is moving.

point of intersection at the instant when the planet's distance therefrom is equal to the planet's distance from the sun multiplied by the ratio of the mass of the planet to the mass of the sun.

The relative velocity of the comet on leaving the planet's sphere of action would be equal to and directly opposite to the planet's velocity ($s=1$), and the comet would be left entirely at rest to fall to the sun. This case could not happen for planets like the earth where mr is less than the semi-diameter of the planet. In the case of the earth mr is less than 300 miles, and actual collision would result. But for Jupiter mr is greater than the distance of the second satellite from the planet. The nearest approach of the comet to the planet would be mr $(\sqrt{2}-1)$ which is more than four times the radius of Jupiter. Hence this case of maximum diminution of major axis could occur near Jupiter.

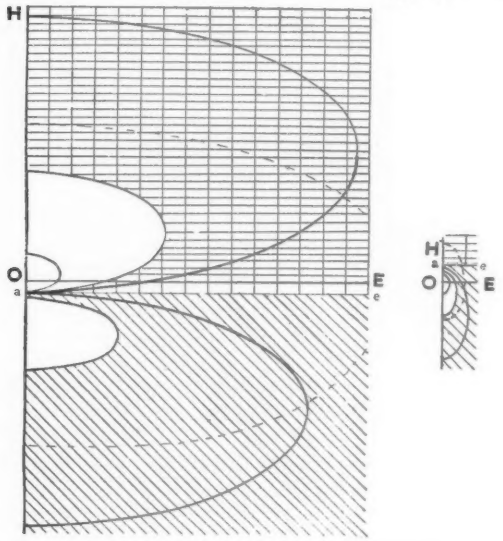
Fig. 2; $\omega=10°$. Fig. 3; $\omega=170°$.



22. *Isergonal ellipse for* $\omega=10°$.—If we make $\omega=10°$ the vanishing points of the isergonal ellipses will be (Table II) at $d=0$, $h=\cdot01250$, and $d=0$, $h=-\cdot15174$. In fig. 2 let OE and OH be the axes of d and h respectively. The vanishing points will be on the axis OH at distances h' and h'' above and below O. Upon this diagram are shown the halves of four isergonal ellipses. The scales used for d and h are not equal to each other, since the use of the same scale for both coördinates would make the figures of inconvenient shape. In this, and in all the figures 2–18, the unit in d is to the unit in h, as 1 to sin ω. But to indicate more clearly this scale, and at the same time to give a kind of shading to a part of the area, there are drawn above the radical axis ae lines parallel to OE, and parallel to OH, at intervals of ·01; that is, the sides of each of the small rectangles in the quadrant HOE are ·01, or about

925,000 miles. Only the positive values of d are represented in the figures. The positive vanishing point being 1·250 of these divisions above O, and the negative vanishing point 15,174 below O, we lay off $Oa=\frac{1}{2}(h'+h'')=-6·962$ divisions, and draw *ae* for the radical axis. The smallest positive value of @ is (Table II) 3·04. As @ increases from 3·04 the ellipse increases in size, and the innermost curve represents what it becomes when @=5. The second curve (separating the blank and shaded areas) corresponds to @=20. Any parabolic comet passing Jupiter with an original angle of $\omega=10°$, and having d and h such as to be represented by a point within the blank area of fig. 2 will leave the vicinity of the planet in an elliptic orbit whose semi-axis major is less than 20, and whose period therefore is less than 90 years.

Fig. 4; $\omega=20°$. Fig. 5; $\omega=160°$.



The larger curve that lies above *ae* in the shaded area is the isergonal ellipse for @=50. As @ increases the lower part of the curve tends to approach the radical axis *ae*, with which it coincides when $@=\infty$. For points in the area below *ae* (distinguished by the oblique-line shading), the planet increases the velocity of the comets, and the comet would be thrown permanently out of the solar system. The smallest semi-transverse axis, the one corresponding to the vanishing ellipse is (Table II) 36·90, and the isergonal curve for @=−50 is drawn in the figure.

23. *Isergonal ellipses for* $\omega=170°$.—In figure 3 are drawn the three ellipses corresponding to the values of @, -5, -20, and -50. The ellipses above *ae* do not appear, inasmuch as the smallest possible elliptic orbit has a semi-axis major of 206·3 (Table II), and a period of about 3000 years. The radical axis *ae* is ·08146 (or over 8 divisions) above OE.

24. Figures 4 and 5 are like diagrams for $\omega=20°$ and $\omega=160°$. With altered numbers the explanations of arts. 22 and 23 apply with slight change to these figures. The line *ae* in figs. 4 and 5 is nearer to OE than is the same line in figs. 2 and 3. In

Fig. 6; $\omega=30°$. Fig. 7; $\omega=150$.

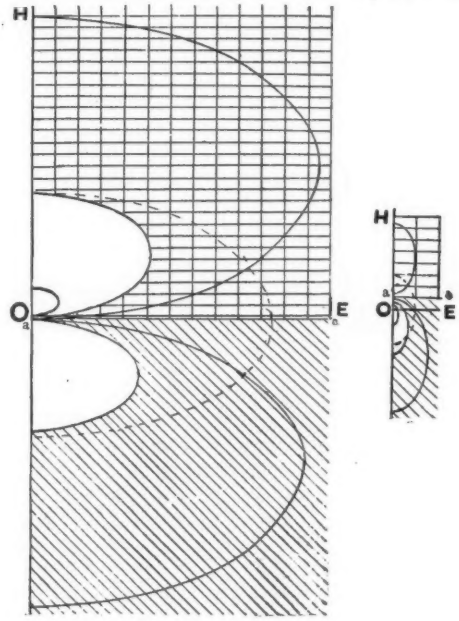


fig. 4 the line for @$=-20$ appears below *ae*, while above *ae* are the three curves for $+5$, $+20$, and $+50$, respectively. In fig. 5 the ellipse for @$=50$ is wanting since the minimum ellipse has a semi-axis major 52·36 (Table II), while below *ae* the three curves are present.

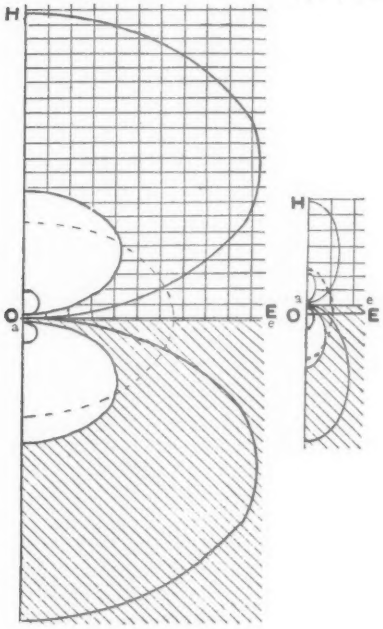
In figures 6 and 7 are contrasted in like manner the isergonal curves for the angles $\omega=30$, and $\omega=$the supplement of 30°. In fig. 6 the curve @$=-5$ is wanting, and in fig. 7 the two curves @$=5$, and @$=20$ are both wanting.

In like manner are to be explained the figs. 8–18. The numbers needed for drawing the figures are furnished by equa-

tion (13). The curves that in each figure separate the shaded area from the non-shaded area are the ellipses for @=20, and @=−20 The shading is introduced in order to compare more readily the corresponding curves in the figures.

25. The dotted curve in the several figures represents those values of d and h for which the total change of direction in the relative orbit is 10°; that is, $\alpha=85°$. It is that curve whose equation is A tan 85°=B, or $d^2+h^2\sin^2\theta=A^2\tan^2 85°$. It is therefore an ellipse whose center is the origin of coördinates, and it is similar in each figure to the isergonal ellipses.

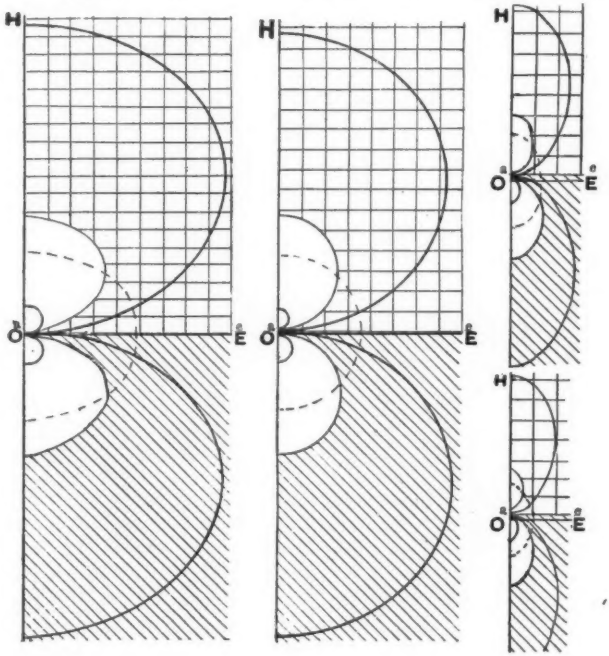
Fig. 8; $\omega=40°$. Fig. 9; $\omega=140$.



26. *Hypotheses about the parabolic cometary orbits.*—It will be convenient to make two assumptions about the distribution of the parabolic comets, and the distribution of the goals of their motions. There seems to be no very well marked relation between the ecliptic, or to speak more strictly the invariable plane of the solar system, and the known parabolic cometary orbits. The following two assumptions do not seem likely therefore to introduce any very serious error into our reasonings.

If about the sun as a center a sphere $\mathfrak{S}$ be described with an arbitrary radius r, it will be *assumed* that near the surface of $\mathfrak{S}$, space is filled equably with comets. We may express this by supposing that in each cubic unit of space near $\mathfrak{S}$, there are at each and every instant n comets. As the orbits are all assumed to be parabolic, the n comets have a common velocity v.

Fig. 10; $\omega=50°$. Fig. 12; $\omega=60$. Fig. 13; $\omega=120°$. Fig. 11; $\omega=130$.



It will be furthermore *assumed* that the directions of the comets in each cubic unit of space near $\mathfrak{S}$ are at random, that is, that the quits and goals of the comet's motions relative to the sun are distributed equably over the surface of the celestial sphere.

27. *Number of comets entering* $\mathfrak{S}$.—If about a normal to $\mathfrak{S}$ as an axis there be described two cones cutting the celestial sphere in two small circles distant from the point where the normal meets the celestial sphere ψ and $\psi+d\psi$, then of the n comets there will be $\frac{1}{2}n \sin \psi d\psi$ comets whose quits are between the two circles. Each of these comets will move perpendicularly to the spherical surface $\mathfrak{S}$ with the velocity

$v \cos \psi$. Hence in a unit of times $\frac{1}{2}nv \cos \psi \sin \psi d\psi$ comets will cross a unit of the surface $\mathfrak{S}$ going towards the sun. The total entering the sphere in the unit of time will be this number multiplied by the number of units in the surface of $\mathfrak{S}$, or

$$4\pi r^2 \int_0^{\frac{\pi}{2}} \tfrac{1}{2} nv \cos \psi \sin \psi \, d\psi = \pi n v r^2.$$

Fig. 14; ω=70.

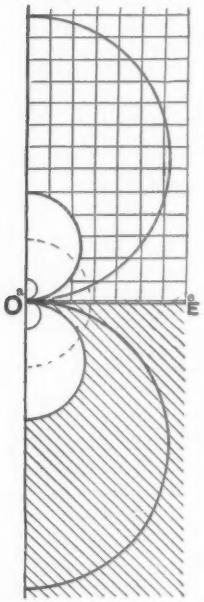
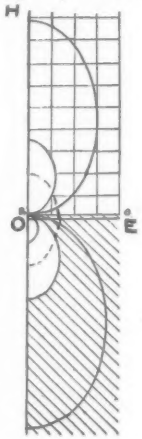


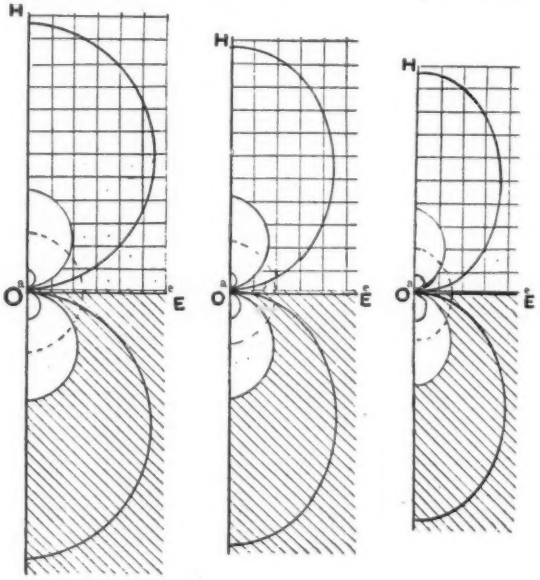
Fig. 15; ω=110.



28. *Distribution of parabolic comets as to perihelion distance.*—This supposition of equable distribution of the goals of comets as they cross the spherical surface $\mathfrak{S}$ involves also a law of distribution of comets as to perihelion distance. The number of comets that enter the sphere in a given time whose motions make with the normal angles between ψ and $\psi + d\psi$ is proportional to $\sin \psi \cos \psi d\psi$. If N be the number of comets that enter $\mathfrak{S}$ in a given period of time with an angle with the normal less than ψ, we may write $dN = k \sin \psi \cos \psi d\psi$, where k is some constant. But if q is the perihelion distance of a comet which at the distance r from the sun moves at an angle with the radius equal to ψ, then $q = r \sin^2 \psi$, and $dq = 2r \sin \psi \cos \psi d\psi$. But comets that enter $\mathfrak{S}$ with angles to the

normal between ψ and $\psi+d\psi$, have perihelion distances between q and $q+dq$. Hence N may also represent the number of comets that in the given period of time pass their perihelia, and whose perihelion distances are less than q. Therefore $\frac{dN}{dq}$ is a constant, and we conclude that if comets be grouped according to their perihelion distances the number of comets whose perihelion distances are less than q is proportional to q.

Fig. 16; $\omega=80°$. Fig. 17; $\omega=90°$. Fig. 18; $\omega=100$.



29. It follows as a corollary to art. 28 that if the two assumptions of art. 26 be made for the spherical surface $\mathfrak{S}$, the like distributions are true for every smaller concentric spherical surface. It would be but a reasonable extension of the assumptions to make them apply to larger spheres, if finite.

[To be continued.]

Art. XVIII.—*Pleistocene Fluvial Planes of Western Pennsylvania;* by Frank Leverett.

In the November number of this Journal there appeared a paper by Mr. P. Max Foshay, entitled "Preglacial Drainage and Recent Geological History of Western Pennsylvania," in which certain views are expressed which do not seem consistent with facts in my possession; and in which, although valuable suggestions are made regarding the possibilities of changes in drainage which the region may have undergone since the beginning of the glacial period, adequate data are not presented to sustain the broad and positive conclusions drawn. It therefore seems important that the subject be further considered and that attention be called to facts which render the problem more complex and its solution less certain than the paper leaves the readers to suppose.

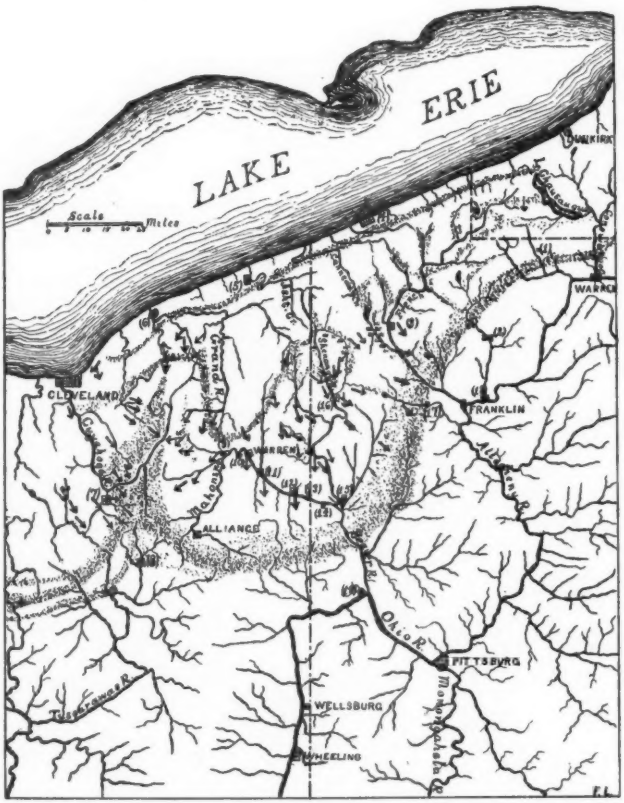
A few general statements respecting the fluvial planes of the region (following essentially President Chamberlin*) will aid in showing the bearing of the facts I wish to present. In the district immediately southeast of the drift-covered portion of western Pennsylvania there are three well-developed fluvial planes distinct from the present flood-planes of the streams, representing as many distinct episodes in recent geological history. The lowest fluvial plane is the rock floor of the valleys, which in much of the region is at a lower level than the beds of the present streams. The middle fluvial plane is represented by the moraine-headed terraces which take their rise in the bulky outer moraine of the "Grand River lobe." These are at a somewhat higher level than the present flood-planes, for the altitude of the region now is such that the streams are deepening their channels. The highest fluvial plane is represented by elevated terraces 250 feet± above the present streams. This is much broader than the middle and lowest planes. Its remnant is a rocky shelf capped with distinctly fluvial material varying in depth up to 40 feet or more. Abandoned loops or "oxbows" occasionally occur, giving a complete cross-profile.

The time sequence of these planes is as follows: the high terraces are the oldest, the moraine-headed terraces are the youngest, while the rock floors of the buried channels are of intermediate age, for they represent the limit of an erosion and deepening that took place after the high terraces were formed and before the moraine-headed terraces were built up.

High-level terraces.—President Chamberlin has set forth in the bulletin referred to the fact that the high terraces were

* Bulletin No. 58, U. S. Geological Survey, pp. 24–37.

fluvial planes as late as the early glacial period. His observations together with the earlier ones of Dr. H. M. Chance of the Pennsylvania Geological Survey, are to the effect that



Explanation of Map.—The shaded portions represent moraines. Their mapping is complete only between the Cuyahoga river and Lake Chautauqua. Striae are represented by arrows and indicate the general divergence from the axes of the lobes. The numbers indicate villages and cities as follows: (1) Lottsville, Penn.; (2) Titusville, Penn.; (3) Meadville, Penn.; (4) Erie, Penn.; (5) Ashtabula, O.; (6) Painesville, O.; (7) Akron, O; (8) Canton, O.; (9) Braceville, O.; (10) Leavittsburg, O.; (11) Niles, O.; (12) Youngstown, O.; (13) Lowellville, O.; (14) Edenburg, Penn.; (15) Newcastle, Pa.; (16) Greenville, Pa., (17) Raymilton, Penn.; (18) Oil City, Penn.; (19) Beaver, Penn.

fluvial material containing crystalline erratics of Canadian derivation occurs along the Allegheny river on this terrace. This determination is of great importance since it brings all

the erosion of the lower 300 feet of the Allegheny valley within the earlier glacial and the interglacial epoch, and throws doubt upon the preglacial age of the buried channels, although they are plainly older than the moraine-headed terraces of this region.

The fact that the Allegheny and Monongahela river-beds had become coated to considerable depth with fluvial débris (40 ft.±) by the close of the earlier glacial period is evidence that the streams had reached a base level at a still earlier date, and makes it probable, though not demonstrative, that the excavation to the level of the upper rock plane of the several lines of drainage which subsequently united to form the Allegheny was preglacial. If not preglacial, it must have been accomplished during the earlier part of the first glacial epoch.

In Mr. Foshay's paper the high level terrace along the Beaver river is discussed as "an old base-level plane," and Professor I. C. White, in his report on Beaver County, Pennsylvania, calls it the "fourth terrace."*

It has been identified by these writers as far north as the mouth of the Connoquenessing where the terminal moraine of the later drift lies upon it. Mr. Foshay calls attention to the important fact that this terrace has a northward descent from the mouth of Beaver river to the terminal moraine, and President Chamberlin has shown that the high terrace of the lower Allegheny and the Monongahela descends with the present streams to their junction not far above the mouth of the Beaver river; all of which evidence favors the hypothesis that the lower factors of the Allegheny river and the Monongahela discharged toward the Lake Erie basin along the course of the Beaver river before the first glacial epoch. This decline of the high level terrace from the mouth of the Beaver north to the point where it is lost under the moraine seems in itself to be good evidence that the old river took this northward course instead of that now followed by the Ohio, and this determination by Mr. Foshay is a valuable addition to our knowledge. It is somewhat short of a conclusive demonstration of the northward course of the stream in the fact that the decline is only 25 feet, that the distance is only ten miles, that the observations are few, (apparently only two), that the two remnants may not belong to strictly identical planes, that the decline is not greater than the possible differential northward depression of the region, and that the non-continuance of the high-level plane down the present course of the Ohio has not been demonstrated. If it shall be shown that no such high terraces follow down the Ohio, the presumption in favor of the

* 2nd Geol. Survey of Penn. Q, pp. 11, 12.

Beaver river route will be strong. If high-level terraces occur, as they doubtless do, on the Ohio between the mouth of the Beaver and Wellsburg, West Virginia, the supposed old divide, and these terraces *decline toward the mouth of the Beaver*, i. e. *contrary to the present stream*, then the demonstration that the old course was to the north through the Beaver valley will be essentially complete.

It is to be hoped that Mr. Foshay, who is practically on the ground, will pursue to a demonstration the hypothesis he has already rendered so highly probable.

As to the course which this old river pursued north of the moraine on the Beaver (assuming that it took this course)—whether along the present route of the Mahoning or that of the Shenango—there seems to be no demonstrative evidence. None of Mr. Foshay's data bear definitely on this point. The Shenango valley all the way from its mouth, 7–8 miles north of where the high-terrace is lost under the moraine, to the Pymatuning swamp on the Erie divide where it connects with the valley of Ashtabula creek flowing into Lake Erie, is broader than that of the Mahoning from its mouth to the Erie divide near Warren, Ohio; its bluffs are less abrupt and its general aspect that of a valley older as well as larger than that of the Mahoning. Moreover the lower Mahoning valley becomes very narrow in the vicinity of Lowellville, Ohio, having abrupt bluffs with a breadth at base of but about one fourth mile, which is too narrow to make it probable that it is a continuation of the old river under consideration, whose breadth above is much greater and whose slopes are more worn and receding. The narrowing at this point fits well the hypothesis that here was the preglacial divide between a stream running northwest into the Grand river basin and one running southeast to join the old river under discussion at the present mouth of the Mahoning. Furthermore, the main preglacial valley of the Grand river basin seems to have entered, not from the southeast along the lower Mahoning but from the south along the upper Mahoning from the direction of Alliance, Ohio, there being a comparatively low belt several miles wide along the upper (north flowing) part of the Mahoning, with low bluffs and a gradual rise both to the east and the west of the river. The relative elevations of the present divides on the Mahoning and Shenango routes respectively, do not help us much in this question, since, in the first place, we cannot trace, or at least have not traced, the terraces which mark the old river bed,—the present surface divide and the present rock divide being matters of more recent formation—and, in the second place, an eastward differential uplift is known to have taken place. The uplift referred to is well shown by the

highest of the beaches in the eastern part of the expanded Lake Erie. This beach is fully 80 feet higher immediately north of Chautauqua lake than it is at the Grand river basin. Since this amount of differential uplift has occurred during the short time since the lake occupied this beach, it becomes necessary to allow for even greater changes either of depression or of uplift in the much longer period that has elapsed since the high-level terraces along the streams of western Pennsylvania were formed.

On the whole, therefore, the balance of evidence favors the Shenango as against the Mahoning route, but the question is still an open one. The definite conclusions of Mr. Foshay supported by map and proposed name do not seem to be warranted by the present state of evidence, or even to represent the probabilities of the case.

Interglacial valleys (*Buried channels*).—As the high-level base-plane has been demonstrably connected with the earlier glacial epoch by Dr. Chance and President Chamberlin, the channels cut in it are obviously of later age; and it is important that the existing broad distinction between the interglacial and preglacial channels of this region be kept in mind; the preglacial channels have, so far as yet identified, a fluvial plane far above that of the present streams, while the interglacial channels have a rock floor in large part below the present streams.

The study of the profiles of the valley floors within this drift-covered region, when combined with an attempt to restore former systems of drainage, is calculated to impress one with the fragmentary nature of available evidence. It is true that portions of Big Sandy, Oil and French creeks and of the Allegheny and Conewango rivers are sufficiently well explored by the numerous oil-well borings to give a satisfactory knowledge of the slope of the valley floors, but outside of the oil district the valleys have been explored only so far as is necessary to obtain water or to prove that oil and gas are not to be found. Throughout much of northwestern Pennsylvania and northeastern Ohio the depth of drift in valleys is known only at intervals of several miles, and very seldom has a series of borings been made that test the entire breadth of a valley.

Mr. Foshay calls attention to the very low altitude of the rock floor near the junction of the Mahoning and Shenango rivers, where it is said to be 50–75 feet below the level of the floor of the Ohio near Pittsburg, and perhaps lower than at the mouth of the Beaver, and bases his "Spencer River" channel largely upon this deep portion of the valley, no borings having yet been made farther up-stream along either the

Mahoning or the Shenango that reveal a rock surface so low as that near the junction of these streams, as may be seen from the following table which represents the deepest borings of which I have knowledge.

Table showing principal borings along the Mahoning-Grand River route.

Location.	Distance.	Altitude.	Drift.	Rock floor.	Authority.
Lawrence Junct., Pa.	0 miles.	760 feet.	150 feet.	610 feet.	White.
Edenburg, Pa.	4·6 "	780 "	200? "	580? "	"
State Line, O. and Pa.	9 "	810 "	80 "	730 "	Newberry.
Lowellville, O.	10·3 "	826 "	? "	? "	
Haselton, near Youngstown	15·6 "	831 "	90 "	741 "	Foshay*
Niles, O.	26 "	854 "	190 "	674 "	" *
Near Southington, O.	40 "	870 "	222+ "	648— "	Leverett.
Mesopotamia, O.	47 "	850 "	208? "	642? "	"
Near Rome	57·5 "	820 "	170+ "	650— "	"

*Given in letter to the writer.

The thickness of drift at Edenburg is a disputed question, some citizens maintaining that the greatest amount penetrated was 140 feet where the level of the well-mouth was 12–20 feet above the river, while others hold the opinion that the drift extends about 200 feet below the river. The borings were made nearly thirty years ago, and no records are known to have been preserved, consequently much allowance should be made for inaccuracies. It may be necessary to add 75 feet to denote the true altitude of the rock floor at this point. However, as there is a possibility that the rock floor is as low as indicated I leave it as given by Prof. White and Mr. Foshay.

The borings at Niles, Ohio (No. 11, on map), are cited by Mr. Foshay as fixing the position of the old channel at that point, if northward differential uplift be taken into account. The amount of differential uplift required if the rock floor is but 580 feet A. T. at Edenburg, is $7\frac{5}{6}$ feet per mile, allowing the stream no fall between Edenburg (No. 14), and Niles; and $9\frac{2}{3}$ feet allowing the stream a fall of one foot per mile, Niles being 12 miles farther north than Edenburg and about 22 miles distant by the stream, while the valley floor there is 94 feet higher than at Edenburg. If we are allowed to assume an uplift of $9\frac{2}{3}$ feet per mile, or even of $7\frac{5}{6}$ feet, nearly every large stream tributary to the Ohio from the State of Ohio, as well as the lower Allegheny and the Monongahela, could be carried into the Lake Erie basin, and we could if we saw fit attach to the Lake Erie basin all the southern tributaries of the Ohio from West Virginia and eastern Kentucky.

In the above calculation a continuous deep channel from Edenburg to Niles is assumed but there is evidence against the validity of this assumption. At Lowellville, Ohio (No. 13), the Mahoning, as has been noted by Dr. Newberry,* has a rocky bed, an examination of the valley at this village for the purpose of finding, if possible, evidence of a deep channel leading through it convinced me that not only is there no evidence of its existence but on the contrary the rock is exposed at frequent intervals throughout the whole width of the valley, the village as well as the river bed being upon rock. The outcrops are so frequent that there appears to be no room for a gorge so much as 100 yards in width, much less for one sufficient to be the outlet of such a stream as must have been discharged by the Monongahela and lower Allegheny rivers. It therefore appears that the hypothesis of a discharge northward along the Mahoning route involves a hypothetical uplift of an improbable amount, wholly unsustained by evidence, and further, that the constriction of the valley at Lowellville makes the route an inherently improbable one.

I have also examined the Shenango valley for the purpose of discovering a northward outlet for the deep channel at Edenburg. The rock floor of this valley is struck at several points about 125 feet below the present stream and seems to slope with the present stream, southward, instead of toward the Erie basin. At Greenville several borings have been made which test quite well the valley throughout its entire width, and no channel of greater depth exists unless it be a narrow gorge inadequate for the passage of a large stream. The level of the lowest part of the valley floor through much of the business portion of the city is about 815 feet A. T. This is 155 feet above the valley floor at Newcastle and at least 160 feet and possibly 235 feet above the rock floor at Edenburg. A calculation of the amount of northward differential uplift that must be assumed and subtracted from the altitude of the valley floor at Greenville to bring it to the lower of the levels at Edenburg gives $8\frac{1}{2}\frac{1}{8}$ feet per mile, and if enough uplift be assumed to give the ancient stream a northward descent of one foot per mile this amount will be increased to about 10 feet per mile,—a greater uplift than it is legitimate to assume.

Additional evidence against the northward discharge of the waters from the great drainage basin of the Monongahela and lower Allegheny some 13,000 square miles in area, may be found in the narrow gorge of the Beaver above Beaver Falls; but the character of the evidence from the Ohio valley itself appears to render unnecessary further consideration of the probabilities of northward drainage. This valley receives

* Geology of Ohio, vol. iii, p. 804.

glacial terraces from its northern tributaries above Wellsburg, West Virginia, and all these terraces continue down the Ohio and have a fall as great as the present stream, showing that an open valley existed previous to the later glacial period and that its stream has since this glacial period been reëxcavating a channel partially filled by glacial gravels. Furthermore, gas well borings at Wellsburg, West Virginia, where Mr. Foshay has placed the old watershed, show the rock floor there to be but 590 feet A. T. or 10 feet lower than it is known to be at any point along the Ohio in Pennsylvania. A carefully prepared report of a well has been sent me by Millard E. Boyd, Esq., city engineer of Wellsburg, in which the character and thickness of drift are given and the altitude of the rock floor is referred to low water in the Ohio, from which it appears that the drift below the level of low water mark is gravel, showing vigorous drainage, and the rock floor is 40·58 feet below low water. Mr. Boyd states that within a radius of two miles about thirty wells have been made and that those on the same bottom with the one reported all show the rock floor to have about the same altitude (590 feet A. T.)

This evidence from the Ohio valley seems conclusive that the Monongahela and Allegheny rivers had their present course down the Ohio in the interglacial period and have held it continuously from that time to the present.

In view of the results arrived at by the study of this portion of the Upper Ohio district, we are naturally led to examine the nature of the evidence put forth by Mr. J. F. Carll some years ago,* as a demonstration that the buried channels of the upper Allegheny, Conewango, Oil, and French creeks have an outlet into the Lake Erie basin. In discussing this evidence the buried channels (interglacial fluvial planes) only are considered and no account is taken of the high terraces (preglacial fluvial planes) since these high planes have not been sufficiently investigated north of the glacial boundary to enable one to form an opinion concerning them.

The numerous oil well borings show that the valley floors of several northern tributaries of the Allegheny have higher altitudes near the mouths of these tributaries than they have a few miles upstream. For example, in the Conewango valley the rock floor is 129 feet lower at Fentonville, near the State line of New York and Pennsylvania, than it is at the mouth of the stream, 13 miles south, and the rock floor of Little Brokenstraw valley is 148 feet lower at Lottsville, Penn. (No. 1), than where its waters join the Allegheny 15 miles below. In other tributaries of the Allegheny the descent of the rock floor begins a few miles above the mouth; thus in Oil creek the

* Penn. 2d Geol. Survey III, 1880, pp. 330–366.

valley floor has its highest point near Titusville, Penn. (No. 2), and there is a descent of 66 feet in eight miles upstream. The valley floor of French creek rises for five or six miles upstream, but near Meadville (No. 3), 25 miles above its mouth, the rock floor is about 150 feet lower than at the mouth of the creek. The floor of Big Sandy creek rises from its mouth to the vicinity of Raymilton (No. 17), but descends above that village, being fully 40 feet lower at Sandy Lake than at Raymilton. Borings are sufficiently numerous to show a strong probability that these valley floors have no channels deep enough to drain them southward, but unfortunately they are not sufficient to demonstrate whether or not there is a continuous descent to the Lake Erie basin from any of the points noted. Mr. Carll has shown that there appears to be no obstacle to the northward continuation of the Conewango valley past Cassadaga lake into Lake Erie, though it is necessary to assume about 500 feet of drift filling at the watershed. Similarly, to give French creek a northern outlet by way of Conneaut lake and Conneaut creek a drift filling of over 300 feet at the watershed north of Conneaut lake must be assumed.

Inasmuch as the northward drainage of these buried channels remains an open question, a brief consideration of other hypotheses to account for the phenomena seems called for. A certain amount of northward descent may prove to be due to crust-deformation. The beaches about Lakes Erie and Ontario, and those of the Glacial Lake Agassiz, as is well known, indicate clearly a northward differential uplift accompanying the retreat of the ice, but they indicate nothing as to the depression that preceded this uplift. In the opinion of those who have given most attention to these beaches, the uplift was due mainly to the withdrawal of the load of ice. This hypothesis involves a previous depression occasioned by its accumulation and an imperfect restoration, owing to the removal of material from portions of the glaciated district and the presence of a load of drift and large bodies of water after the ice withdrew in parts of the glaciated district not thus encumbered in preglacial times. So far as we may reason from theoretical grounds, there should be expected a residuum of northward depression in the region under discussion, since a large amount of drift was deposited here. And this may prove to have been an important factor in giving these valley floors a northward slope, though it is hardly probable that it was the chief one.

A more important factor in the production of the peculiar valley phenomena of this region may prove to have been erosion effected beneath the ice either by the ice itself or by subglacial waters. Whether the ice greatly deepened valleys

through which it flowed is an open question, but that subglacial waters exerted a peculiar eroding power in certain places near the ice margin is conclusively shown in various parts of the glaciated district by the presence of large channels made by them. Some of these are remote from present streams and have been little affected by post-glacial erosion. Their trend is in line with the striation and approximately at right angles with the moraine. They are often occupied by osars and hence are called "osar troughs." These troughs or channels sometimes rise toward the moraine at the rate of several feet per mile, and yet the material in the osars lying in them shows conclusively that the flow was in that direction. The water seems to have been forced upward toward the ice margin by the weight of the ice sheet and by hydrostatic pressure. These osar troughs were formed just before the ice made its final retreat, but the eroding power, of which they are the product, was probably in operation in earlier stages of the ice invasion. The outer moraine in the district under discussion is a complex one, the equivalent of several moraines farther west that indicate a succession of advances and retreats of the ice front. In the early stages the rock floors of these valleys may have been deepened in places by the subglacial streams in the same manner as the osar troughs were produced. By reference to the accompanying map it will be seen that every valley in which a very low rock floor has been reported has a trend approximately at right angles with the moraine and in line with the ice movement; that is, such a trend as to invite the flow of ice and of subglacial waters. Furthermore it appears that in every case the lowest known point of the rock channel in these several valleys is near the inner border of the moraine. In case it is found that no northward outlets exist the most plausible explanation for the low altitude at these points would seem to be a deepening of the channels here below their main outlets by subglacial waters assisted, perhaps, by the ice itself.

Summing up all the available evidence, it appears that no northward outlets have been found for the low channels just within the moraine on these several streams which are not embarrassed, either by a rise in the rock floor or an extraordinary amount of drift. In the streams under special consideration, the Shenango, Mahoning and Beaver, it appears that the rock floor rises in all directions from Edenburg, unless there be a descent down the Beaver. The obstacles to a northward discharge of these streams seem, on the whole, greater than those in the way of a southward discharge. In the Monongahela, lower Allegheny and the Ohio valleys, the available evidence all indicates southward discharge along the present course of the Ohio from the interglacial period to the present time.

Taking into consideration all the known facts, it certainly seems premature to urge, without distinct qualification, the acceptance of a hypothesis of northward drainage for any of these streams during the interglacial epoch, and much more so to impose a name for the unproven river.

Moraine-headed terraces.—President Chamberlin's description of the moraine-headed terraces and general remarks upon the history of the several fluvial planes embody so well the essential facts that further remarks are unnecessary. From his paper the following extracts are taken verbatim.*

"The third group of terraces are sharply distinguishable from those which have just been considered; first, in the fact that, instead of being rock platforms covered by fluvial material, they are made up bodily of coarse alluvium, mainly gravel. They have their chief development in the rivers entering the Ohio from the north, and when traced up they are found to head on one of the moraines of the later glacial epoch, or at least of a later glacial epoch following at a considerable interval an earlier one. The uppermost of these terraces has for its surface plane the ancient flood deposits of the glacier-fed streams. The lower terraces have been cut out of it by subsequent erosion. Near the moraine this upper glacial flood surface may be traced continuously, rising somewhat rapidly as the moraine is approached, and passing gradually into a series of undulations which merge into the gravelly knobs and basins, and thence into the unassorted hills of the moraine. This relationship was satisfactorily observed by Mr. Gilbert and myself, separately or jointly, on Conewango creek, near Russellburg; on the Little Brokenstraw, near Freehold; on the Big Brokenstraw, near Horn's Siding; and on Oil creek near Hydetown. On Sugar creek, French creek, and Sandy creek phenomena of similar significance appear, but they are less clear in their import. On Beaver river and Little Beaver creek analogous features are more satisfactorily displayed.

The streams of gravel starting in these morainic heads run down through the rock channels cut below the old river bottom as above described. The surfaces of these later glacial gravel streams are generally much below that of the earlier terrace deposits, but as they slope more rapidly there is no constant difference. An interval of from 100 to 200 feet may be taken as representative. The bottom of these later glacial gravels extends below the present river-beds, reaching depths varying from 40 feet to 250 feet or more, showing a considerable depth of channel before this late filling. These terraces reach their greatest height above the present stream, so far as observed, at the junction of the Beaver river with the Ohio. There the

* Bulletin No. 58, U. S. Geol. Sur., 1890, pp. 32–36.

terrace rises 127 feet above the Ohio, according to a lock-level measurement by Mr. Gilbert.

Similar moraine-headed terraces occur in Ohio on the Muskingum, Scioto, and Mad rivers and their tributaries, and seem to have their equivalent in terraces on the lower stretches of these rivers and on the Ohio. In other words, there is a general system of deep valley gravels, starting from the moraines indicated and sweeping down the valleys, growing progressively finer in material. Out of these glacial flood deposits a system of terraces has been cut by subsequent erosion. The still later glacial episodes seem to have introduced modifying elements, but these are unimportant in this connection.

The time and manner of origin of the moraine-headed terrace planes are placed beyond question by their morainic connections. They are clearly the products of the streams that issued from the glacier during the moraine-forming epoch. The carving of the terraces out of these planes was chiefly a subsequent work, of relatively minor importance in the present discussion. The coarseness of the gravels of this series indicates vigorous drainage, which in turn implies an open valley and at least a fair gradient below. It is equally evident that terraces of a much higher level and different gradient could not have been formed at the same time. Minor side-valley terraces might have been formed at flood stages, but only to the height of the maximum floods, and these must have had the same slope as the broad flood planes.

It is clear that the upper gravel-bearing terraces were not formed at the same stage as these moraine-appended ones, for they are not only of a different type, being alluvium-covered rock platforms, but they stand high above most of the morainic heads of the later deposits and show much greater antiquity in the erosion of their surfaces. For example, at Warren the old gravels have an altitude of 1415 feet above sea-level, with a terrace at 1395 feet, while the moraine-headed flood deposits of the later epoch at Russellburg, eight miles upstream, occur at about 1275 feet. On the Beaver river the moraine-headed gravel stream has an elevation of about 830 feet, while along the valley below pebbles referred to the earlier epoch range from 900 to 950 feet, and ten miles below there is a wide rock-based terrace at about 885 feet. But these higher gravels contain pebbles of granite and other crystalline rock, whose presence is only to be accounted for through glacial agencies, and the explanation of their origin must embrace that element."

"The higher glacial gravels antedated those of the moraine-forming epoch by the measure of the erosion of the channel through the old drift and the rock, whose mean depth here is about 300 feet, of which, perhaps, 250 may be said to be rock.

The excavation that intervened between the two epochs in other portions of the Allegheny, Monongahela, and Upper Ohio valleys is closely comparable with this.

In view of these facts it seems scarcely less than proven that it was the earlier invasion of ice that reversed the drainage and partially filled the valleys with debris, forming the capping of glacial gravel that rests upon the upper terrace."

"From the fact that the fluvial material in these abandoned channels and on the corresponding terraces in the Monongahela valley is wholly local, or southern, while among the analogous material of the Allegheny there mingle crystalline erratics of Canadian derivation, and from the evidence given above, we draw the inference that the partial filling was coincident with some stage of the earlier glaciation, presumably a late stage. This view gathers some support from the now well sustained belief that a general depression and slackening of drainage accompanied the earlier glaciation.

Following this episode of valley-filling and earlier glaciation there was a prolonged epoch of rapid erosion of the valley bottom, which was apparently coincident with an interglacial epoch, and was, perhaps the result of the resilience of the land after the glacial depression. During this epoch the rock gorges were cut down to the rock bottoms that now lie forty feet or more below the present river bottoms. Then came the later invasion that halted at the outer terminal moraine, whose overloaded floods, like those of the preceding glacial incursion, filled the valley bottoms with glacial alluvium; only, in this instance, in harmony with the more vigorous character of the later glaciation, the filling reached, at some points, 300 feet. Since that time there has been another stage of reëxcavation, giving origin to the lower gravel terraces.

This is doubtless far from being the whole history of events, and may be divergent from the truth in minor phases, but I believe with some confidence that it represents the general truth respecting the history of the abandoned channels and chief terrace deposits of the system of benches under consideration."

Madison, Wis., March 14, 1891.

Art. XIX.—*A method for the Determination of Antimony and its condition of Oxidation;* by F. A. Gooch and H. W. Gruener.

[Contributions from the Kent Chemical Laboratory of Yale College.—VIII.]

Bunsen's method of determining qualitatively the condition of oxidation of salts of antimony, by boiling these substances in solution with potassium iodide and hydrochloric acid and noting whether the liquid takes the color of free iodine, has been applied successfully to the quantitative determination of antimony in its highest condition of oxidation by Weller,* who distils the iodine from the solution, collects it in the distillate and, determining it volumetrically, calculates from the amount of it found the antimonic salt which sets it free according to the equation

$$SbCl_5 + 2H\text{-}I = SbCl^3 + 2HCl + I\text{-}I.$$

The advantage of treating the residue, rather than the distillate, in analytical processes in general which involve distillation is so obvious as to constrain us to seek conditions under which Bunsen's reaction may be applied in such manner that the antimony shall be held and estimated directly in the residue. The general plan of work was laid down in a similar process elaborated in this laboratory for the reduction of arsenic acid.† According to this process the arsenic to be reduced is taken in a solution of appropriate dilution, and treated with sulphuric acid in adjusted amount and an excess of potassium iodide. The liquid thus prepared is boiled to a definite degree of concentration, the iodine then remaining unexpelled, if any, is bleached by the very careful addition of dilute (centinormal) sulphurous acid, and the liquid is immediately diluted and neutralized. After cooling, the reduced arsenic is titrated by standard iodine in presence of starch.

We found in preliminary experimentation that the same general plan of treatment is available in the handling of antimonic compounds, but it is necessary to take precautions to prevent the deposition of the antimony from solution upon the addition of the sulphuric acid. Tartaric acid accomplishes this effect satisfactorily and does not, as the result proved, introduce undesirable complications. It transpired also that the dilution of the solution at which the crystalline iodide or oxyiodide separates out during the boiling is greater than is the case when similar amounts of arsenic are dealt with. It appeared, for example, that concentration to 45cm.^{3} was sufficient to cause crystallization and slight sublimation when the

* Ann. d. Chem. u. Pharm., ccxiii, 246.

† Gooch and Browning, this Journal, xl, p. 66.

amount of antimonious oxide present (with excess of potassium iodide and 10cm.³ of sulphuric acid, 1 : 1) was approximately 0·2 grm. Otherwise the process as employed in the reduction of arsenic appeared to be applicable to the similar treatment of antimony.

The following quantitative experiments were undertaken to discover the condition of concentration best suited to the reduction of antimonic salts under circumstances otherwise like those adapted to the reduction of arsenic, and to test the perfection of the process. Definite amounts of tartar emetic, purified by recrystallization, were used to make the antimonic salt to be afterward reduced, the antimony being raised to the highest degree of oxidation by titration with standard iodine after the addition of sodium tartrate (to prevent the precipitation of the antimony during the process of oxidation) and hydrogen sodium carbonate in the usual excess. In this process starch was sometimes employed to give the end reaction, and sometimes reliance was placed upon the appearance of the color of free iodine, experience having indicated that the use of the starch is not essential when the solutions are sufficiently small in volume, though as a matter of course, the correction demanded for the excess of iodine necessary to give color to the body of liquid is greater when starch is not used.

This treatment of the tartar emetic served the double purpose of providing a perfectly definite antimonic salt and restandardizing the solution of standard iodine, which was to be used subsequently in reoxidizing the antimony after its reduction, against the tartar emetic; and thus the imperfection of the process, whatever it may be, whether in the reduction or elsewhere, becomes apparent and is measured immediately by the difference between the amounts of iodine employed in the two oxidations. This mode of standardizing the iodine appears to be peculiarly advantageous in view of Fresenius's demonstration* that the iodometric estimation of antimony yields too high results, at least in the case of tartar emetic, when the standard iodine is standardized in the usual manner and, as is undoubtedly best, the characteristic starch-blue is taken for the end reaction rather than the premonitory and somewhat indefinite reddish tint.

The larger amounts of tartar emetic were weighed out dry; the smaller quantities were secured by measuring out definite portions of a solution of fixed strength. To every portion was added, in an Erlenmeyer beaker of 300 cm.³ capacity, one gram of tartaric acid previously treated with an excess of hydrogen sodium carbonate, and the oxidation was effected, as described, by iodine dissolved in potassium iodide to a solution

*Quant. Anal. 6te Aufl., 817.

approximately decinormal. Four grams of tartaric acid were added, and dilute sulphuric acid, if the solution still remained alkaline, to faint acidity. In addition 10 cm.^{3} of a mixture of sulphuric acid and water in equal parts were introduced, and the liquid was boilied after introducing a platinum spiral to prevent bumping, and a trap made of a two-bulb drying tube cut short and hung, large end downward, in the mouth of the flask, to prevent mechanical loss. At the chosen degree of concentration, determined by marks upon the flask, the boiling was stopped, the color bleached by the cautious addition of sulphurous acid (approximately centinormal), and the solution, nearly neutralized with sodium hydrate, made alkaline by hydrogen sodium carbonate added in an excess amounting to about 20 cm.^{3} of the saturated solution, was titrated with the standard (decinormal) iodine after the addition of a fresh portion of starch.

Table I, contains the account of experiments in which the larger amounts of antimony were employed.

TABLE I.

Final volume.	Tartar emetic taken.	Sb_2O_3 taken.	Iodine used in final oxidation.	Sb_2O_3 found.	Error.
cm.^{3}	grm.	grm.	grm.	grm.	grm.
100	0·5021	0·2178	0·3522	0·2004	0·0174 −
80	0·5030	0·2181	0·3784	0·2153	0·0028 −
60	0·5008	0·2172	0·3768	0·2144	0·0028 −
60	0·5010	0·2173	0·3780	0·2151	0·0022 −
60	0·5010	0·2173	0·3809	0·2168	0·0005 −
55	0·5023	0·2178	0·3827	0·2178	0·0000
55	0·5015	0·2175	0·3806	0·2166	0·0009 −
50	0·5007	0·2172	0·3814	0·2171	0·0001 −
50	0·5039	0·2185	0·3839	0·2185	0·0000
45	0·5001	0·2169	0·3818	0·2173	0·0004 +
45	0·5004	0·2170	0·3825	0·2176	0·0006 +

The results of these experiments indicate unmistakably that complete reduction may be brought about under the conditions, but that concentration to a volume of from 45 cm.^{3} to 55 cm.^{3} during the boiling is not only advantageous but necessary. The mean error of the determination in which the final volume fell within these limits was zero between limits of 0·0009 grm. − or 0·0006 grm. +. In both determinations in which a final volume of 45 cm.^{3} was reached, and in one of the experiments in which the final volume was 50 cm.^{3}, the formation of the crystalline antimonious iodide or oxyiodide in the liquid was noted, and the deposition of a very slight sublimate of the same salt in the trap. It is evident, therefore, that it would be hazardous to attempt to push the concentration further.

In all these experiments hydriodic acid was present in amount equivalent to 1·1 grm. of potassium iodide—0·5 grm. introduced as iodine and 0·6 grm. introduced as such in the standard iodine where it plays the part of solvent.

In the experiments recorded in Table II, smaller amounts of antimony and correspondingly smaller quantities of the oxidizing solution were employed; otherwise, the same general mode of proceeding was followed. The limits of concentration fixed upon were, however, varied somewhat. The previous experiments showed plainly that anything like a complete reduction of the antimony could not be anticipated when the final volume was greater than 60 cm.^{3}, and the experience with the smaller amounts of antimony treated in the second series pointed to the fact, as the work progressed, that for them the crystallization and sublimation did not occur until the concentration had brought about a decrease in volume to 35 cm^3. The limits of final volume were placed therefore, for these experiments, at 60 cm.^{3} and 35 cm^3. Centinormal iodine was used for the oxidations and bleaching with sulphurous acid was found to be unnecessary, the amount of iodine liberated in these experiments being so small as to vanish in the concentration so completely that no color was visible (nor was it brought out by starch) after washing down the trap and cooling. There did remain a trace of color before the addition of the water but this seemed to us to be due in all probability to the incipient formation of the antimonious iodide or oxyiodide which is decomposed by the action of more water. At all events it disappeared on the addition of water and no reoxidation of the antimony was found subsequently.

TABLE II.

Final Volume.	Tartar Emetic taken.	Sb_2O_3 taken.	Iodine used in final oxidation.	Sb_2O_3 found.	Error.
cm^3.	grm.	grm.	grm.	grm.	grm.
60	0·0500	0·0217	0·0239	0·0136	0·0081—
60	0·0500	0·0217	0·0258	0·0147	0·0070—
60	0·0500	0·0217	0·0261	0·0148	0·0069—
50	0·0500	0·0217	0·0316	0·0180	0·0037—
40	0·0500	0·0217	0·0385	0·0219	0·0002+
35	0·0500	0·0217	0·0380	0·0216	0·0001—
35	0·0500	0·0217	0·0381	0·0217	0·0000
35	0·0500	0·0217	0·0382	0·0218	0·0001+
35	0·0500	0·0217	0·0382	0·0218	0·0001+

These results show that for the smaller amounts of antimony the reduction was completed only by pushing the degree of concentration somewhat lower than was found to be necessary

in treating the larger amounts. The only point in which these experiments differ essentially from those of the previous series is in the quantity of the iodine solution employed to effect this oxidation. So far as concerns the free iodine itself the conditions are similar in both series; for the iodine is converted in both cases to hydriodic acid exactly equivalent in amount to the antimony acted upon. The potassium iodide which is added in the iodine solution produces by action upon the sulphuric acid present an excess of hydriodic acid, which is, of course, dependent upon the absolute amount of the iodine solution employed. The hydriodic acid is the active agent in the reduction of the antimony, and to the greater mass-action in the former series of experiments might be attributed the more complete reduction for equal degrees of concentration. Accordingly the determinations of Table III were made to put this point to the test. In these experiments the conditions were identical with those of the determinations of Table II, excepting that in every case 1 grm. of potassium iodide was added to the liquid before boiling, thus bringing the total amount of hydriodic acid present to an equality with that present in the experiments of Table I, in which the larger amounts of antimony were treated. The results of these experiments bear out completely the hypothesis concerning the mass-action of the hydriodic acid—the smaller amounts of antimony being completely reduced in the presence of the large excess of hydriodic acid even at a final volume of 60 cm.^{3} with a maximum error of 0·0002 grm.—

TABLE III.

Final Volume.	Tartar Emetic taken.	Sb_2O_3 taken.	Iodine used in final oxidation.	Sb_2O_3 found.	Error.
cm.^{3}	grm.	grm.	grm.	grm.	grm.
60	0·0500	0·0217	0·0378	0·0215	0·0002—
60	0·0500	0·0217	0·0379	0·0216	0·0001—
60	0·0500	0 0217	0·0379	0·0216	0·0001—

It is plain therefore that we have in the phenomena described the basis of a good method for the iodometric determination of the condition of oxidation of antimony; for, the amount of antimonious salt present in a mixture of antimonious and antimonic salts may be determined by direct titration in alkaline solution, and the total amount of antimony present is given similarly after the treatment by boiling, as described, with potassium iodide and sulphuric acid, the amount of antimonic salt being immediately calculable from the difference between the quantities of the standard iodine used as the

oxidizer before and after reduction. The best method of proceeding appears to be that in which the concentration was restricted so that the point of sublimation and crystallization was not reached and in which the presence of an excess of potassium iodide was assured.

It seemed desirable, in this connection, to test the applicability of the method, as outlined, to the reduction and estimation of antimony and arsenic associated together, as so often happens in practice. The preceding experiments establish the fact that it is undesirable to attempt, in treating antimony, to force the concentration of the solution below 50 cm.^{3}, under the conditions laid down and when the amount of antimony present is equivalent to the maximum with which we have experimented, about 0·2 grm. of antimonious oxide. In the parallel process for the determination of arsenic concentration to 40 cm^3 was recommended in all cases (the maximum amount treated being equivalent to about 0·33 grm. of arsenious oxide), but it was not shown in the elaboration of that process that reduction would not take place at a concentration not quite so extreme. In the results recorded in Table V, which relate to experiments which duplicate the conditions found most favorable to the reduction of varying amounts of antimony,—the presence of the equivalent of 1·1 grm. of potassium iodide, and concentration to 50 cm^3—and differ from these only in the fact that arsenic was associated with antimony in every case, it appears that the reduction of arsenic may be effected simultaneously with that of the antimony.

TABLE IV.

Final Volume.	Tartar Emetic taken.	Sb_2O_3 taken.	As_2O_3 taken.	Iodine used in first oxidation.	Iodine used in final oxidation.	Difference between the amounts of iodine used in the two oxidations.	Error in terms of Sb_2O_3	Error in terms of As_2O_3.
cm.^{3}	grm.	grm.	grm.	cm.^{3}	cm.^{3}	cm.^{3}	grm.	grm.
50	0·1530	0·0870	0·0500	19·37	19·43	0·06+	0·0004+	0·0003−
50	0·1503	0·0855	0·0495	19·05	19·02	0·03−	0·0002−	0·0001−
50	0·1503	0·0855	0·0544	20·05	19·97	0·08−	0·0006−	0·0004−
50	0·1503	0·0855	0·0495	19·05	19·00	0·05−	0·0004−	0·0003+

It is plain that the error in these results, whether reckoned as falling upon the antimonious oxide or upon the arsenious oxide, is quite within the limits allowable in volumetric determinations by means of decinormal solutions. One point, however, in the determination of the combined amounts of antimony and arsenic by the method here proposed deserves special consideration. It has been shown in the work to which reference has been made that arsenic is reducible by the pro-

cess outlined and determinable with accuracy by titration with iodine standardized against arsenious oxide. In this later work we show that antimony may be reduced similarly and estimated satisfactorily by titration against iodine standardized against tartar emetic. These two methods of standardizing do not yield identical results, and so we are confronted with an inherent error in the process for estimating antimony and arsenic at once, which cannot be overcome unless the individual amount of one or other constituent may be otherwise determined. If the determination of either the arsenic or antimony is possible it is, of course, easy to calculate with the use of the appropriate standard the amount of the solution of iodine which is really engaged in the oxidation of this particular constituent, and the remainder of the iodine actually employed, gauged by the second standard, will give the corrected amount of the second constituent.

In case no such correction is feasible it becomes a matter of interest to note the magnitude of possible error. Our experience, based upon many determinations throughout the course of the work detailed above, pointed to a difference in the value of the two standards amounting to about one-half of one per cent. If, therefore, the weight of reduced oxide amounts to the maximum which we have experimented with—about 0·2 grm.—the greatest possible error will be 0·0010 grm.+ or 0·0010 grm. −, according as the entire 0·2 grm. is antimonious oxide estimated by the arsenic standard, or arsenious oxide estimated by the tartar emetic standard. The essential features of the process which we propose for the reduction of antimony and the determination of its degree of oxidation are recapitulated briefly in the following statement.

The salt of antimony, not exceeding the equivalent of about 0·2 grm. of antimonious oxide, is titrated, in presence of 1 grm. of sodium tartrate and the usual excess of sodium hydrogen carbonate, by means of iodine standardized against tartar emetic. The result of this titration gives the amount of antimonious salt present. To the solution are then added 4 grms. of tartaric, dilute sulphuric acid, if necessary, to neutralization, an excess of 10 cm.^{3} of half and half sulphuric acid, and enough potassium iodide so that there shall be present of hydriodic acid the equivalent of a little more than 1 grm. of the iodide. The liquid is diluted to 100 cm.^{3}, boiled in an Erlenmeyer beaker until the volume is decreased to 50 cm.^{3}, the precaution being taken to introduce a platinum spiral to prevent bumping and a trap, as described, to obviate mechanical loss. The color remaining after concentration, if there be any, is bleached by dilute sulphurous acid (approximately centinormal). The solution is nearly neutralized with

sodium hydrate, treated with an excess of sodium hydrogen carbonate amounting to 20 cm.³ of the saturated solution, cooled, and titrated in presence of starch by the standard iodine. This final titration gives, of course, the entire amount of antimony present. The difference between the indications of the two titrations is the measure of the antimony in the higher condition of oxidation. The method as outlined is accurate and rapid, and so simple as regards manipulation that a number of determinations can be carried through simultaneously with the use of ordinary apparatus.

Art. XX.—*A Method for the Estimation of Chlorates;* by F. A. Gooch and C. G. Smith.

[Contributions from the Kent Chemical Laboratory of Yale College.—VII.]

It has been shown in recent work in this laboratory* that under conditions properly controlled, arsenic acid in excess is capable of expelling the iodine from hydriodic acid at the boiling temperature of the solution, being itself reduced correspondingly according to the equation

$$H_3AsO_4 + 2H\text{-}I = H_3AsO_3 + H_2O + I\text{-}I.$$

On cooling the liquid remaining after such treatment, and neutralizing, the arsenious oxide produced in the reaction may be reoxidized iodometrically in the usual manner, the iodine added to accomplish this purpose being the exact measure of the iodine originally present as hydriodic acid and expelled from the acid solution during the process of boiling.

If other sufficiently energetic and easily decomposable oxidizing agents are present at the same time with the arsenic acid, it would be natural to suppose that these substances will act similarly upon the hydriodic acid, and, furthermore, that the oxidizing power of the arsenic acid will not be called into play until that of the more unstable oxidizers has been exhausted. Chloric acid, for example, acts with great ease upon hydriodic acid, and it would be natural to suppose that in a mixture of chloric, hydriodic and arsenic acids the mutual action of the chloric and hydriodic acids will be manifest first and will go on steadily to completion, and that when this effect is accomplished, and then only, the action of the arsenic acid in liberating iodine from the residual hydriodic acid and in registering by its own reduction the amount of iodine thus set free will appear. It should be possible, therefore, if this theory of the reaction between these substances is correct, to found upon the method referred to for the estimation of iodine

* Gooch and Browning; this Journal, xxxix, p. 188.

a method for the estimation of chlorates—this to consist in heating the chlorate, in acid solution and under conditions otherwise appropriate, with a known amount of potassium iodide, somewhat in excess of that theoretically equivalent to the chlorate, and in presence of an excess of arsenic acid, the arsenious oxide produced in the process being determined iodometrically and serving to measure the amount of iodide left undecomposed by the chlorate. Of course, the difference between the amount of iodide left undecomposed and that originally introduced should be the measure of the chlorate entering into the reaction. That a better form of iodometric method than those we have had heretofore for the estimation of chlorates is desirable is obvious when it is recognized that Bunsen's original process—consisting in heating the chlorate with hydrochloric acid and potassium iodide, distilling and estimating the iodine collected in the distillate—fails (owing to the formation of the comparatively non-volatile iodine chloride in the simultaneous action of the oxidizer upon hydrochloric and hydriodic acids) to show the entire amount of iodine corresponding to the chlorate; and that Finkener's substitute for this process—which prescribes the heating of the chlorate, under pressure in a closed bottle and in an atmosphere of carbon dioxide, with a mixture of hydrochloric acid and potassium iodide previously prepared by treatment with sulphurous acid, boiling and subsequent cooling in an atmosphere of carbon dioxide—though excellent when properly carried out, demands careful preparation of materials and skillful handling in the execution.

We have studied the applicability of the process outlined above and record our experience in the following account.

A solution of potassium iodide, approximately decinormal, was standardized according to the method to which reference has been made and which may be summarized in brief, as follows: Portions of this solution were measured from a burette into Erlenmeyer beakers capable of holding 300 cm.^{3}, 2 grms., approximately, of pure dihydrogen potassium arseniate were added in solution, 20 cm.^{3} of a mixture of sulphuric acid and water in equal volumes were introduced with enough water beside to increase the entire volume to a little more than 100 cm^3. A platinum spiral was introduced to secure quiet boiling, a trap made of a straight two-bulbed drying tube cut short was hung with the larger end in the neck of the flask, and the liquid was boiled until the level had reached a mark upon the flask indicating a volume of 35 cm.^{3}, experience having shown that this degree of concentration is sufficient and that it is best not to exceed it. The liquid remaining was cooled and nearly neutralized by sodium hydrate, acid potassium carbonate

was added to alkalinity, 20 cm.³ of a saturated solution of this salt were added in excess, and the arsenious oxide in solution was titrated by standardized decinormal iodine in presence of starch. The iodine added in the reoxidation of the arsenious oxide was taken as the exact equivalent of the iodine expelled in boiling. Several closely agreeing determinations made in this manner served to fix the standard of the solution.

The action of chloric acid under similar conditions was tested by following out exactly the process employed in standardizing the iodide, with the exception that weighed amounts of potassium chlorate, purified by recrystallization, were also introduced and that the precaution was taken to have the potassium iodide present in every case to an amount at least eight and a half times as great as that of the potassium chlorate —this amount being a little more than the equivalent weight of the iodide referred to the chlorate. The experiments involved amounts of the chlorate ranging from 0·2 grms. to 0·01 grm., and quantities of the iodide varying from eight and a half to fifty times those of the chlorate. The results with all essential details are contained in the following table:

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
H_2SO_4 [1 : 1] taken.	H_2KAsO_4 taken.	KI = I taken.	KI = I taken.	Iodine corresponding to As_2O_3 reduced.	Difference between Iodine taken and Iodine added to oxidize As_2O_3.	$KClO_3$ taken.	$KClO_3$ found,—that is, equivalent to I in column VI.	Error.
cm.³	grm.	grm.	grm.	grm.	grm.	grm.	grm.	grm.
20	2	2·0092	1·5356	0·2962	1·2394	0·2000	0·2000	0·0000
20	2	2·0092	1·5356	0·2973	1.2383	0·2000	0·1999	0·0001—
20	2	1·0380	0·7934	0·0570	0·7364	0·1185	0·1188	0·0003+
20	2	0·8706	0·6654	0·0435	0·6219	0·1000	0·1004	0·0004+
20	2	9·8706	0·6654	0·0429	0·6225	0·1000	0·1005	0·0005+
20	2	0·8706	0·6654	0·0435	0·6219	0·1000	0·1004	0·0004+
20	2	0·8706	0·6654	0·0435	0·6219	0·1000	0·1004	0·0004+
20	2	0·5023	0·3839	0·3208	0·0631	0·0100	0·0102	0·0002+
20	2	0·5023	0·3839	0·3201	0·0638	0·0100	0·0103	0·0003+
20	2	0·2009	0·1536	0·0889	0·0647	0·0100	0·0105	0·0005+
20	2	0·2009	0·1536	0·0903	0·0633	0·0100	0·0102	0·0002+
20	2	0·2009	0·1536	0·0903	0·0633	0·0100	0·0102	0·0002+
20	2	0·1339	0·1024	0·0405	0·0619	0·0100	0·0100	0·0000
20	2	0·1004	0·0768	0·0157	0 0611	0·0100	0·0099	0·0001—
20	2	0·1004	0·0768	0·0182	0·0586	0·0100	0·0095	0·0005—

The mean error of these determinations is a little less than 0·0002 grm +, between extremes of 0·0005 grm. + or 0 0005 grm. —, and the results are evidently excellent for an iodometric process in which titration is effected by decinormal solutions. An excess of iodide over an amount a little in excess of the equivalent proportion is without effect. The process is rapid and easy.

The paper upon the determination of iodine, to which reference has been made and upon which this process is based, prescribes corrections for the volatility of arsenious chloride and the slight deoxidation of arsenic acid when chlorides and bromides are also present in considerable amount. In this process, however, the amount of hydrochloric acid evolved from the maximum weight of chlorate treated—0·2 grm. of the potassium salt—calls for a correction so small as to be insignificant.

Art. XXI.—*Dampening of Electrical Oscillations on Iron Wires;* by John Trowbridge.

[Presented to the American Academy of Sciences, May 27, 1891.]

It has generally been assumed by those who have studied the subject of very rapid oscillations of electricity, such as occur in Leyden jar discharges, that the magnetic character of the conductor has very little influence upon the character of the discharge. Thus, in a note to an article on electrical waves, W. Feddersen states that electrical oscillations may suffer a slight weakening on iron; but this diminution is very slight:—

"Beim Eisen könnte in Folge der Magnetisirungen eine Abweichung hervortreten; in dess zeigt der Versuch, dass dieselbe keinenfalls bedeutend ist, übrigens in dem Sinne erfolgen müsste, als wenn die Elektricität beim Eisen ein grössere Hinderniss fände, wie bei den übrigen Metallen."*

In Dr. Lodge's treatise on Modern Views of Electricity (ed. 1889), we find the following:—

"But in the case of the discharge of a Leyden jar iron is of no advantage. The current oscillates so quickly that any iron introduced into its circuit, however subdivided into thin wires it may be, is protected from magnetism by inverse currents induced in its outer skin, and accordingly does not get magnetized; and so far from increasing the inductance of the discharge circuit, it positively diminishes it by the reaction effect of these induced currents; it acts, in fact, much as a mass of copper might be expected to do." (p. 365.)

Fleming writes as follows:

"With respect to the apparent superiority of iron it would naturally be supposed that, since the magnetic permeability of iron bestows upon it greater inductance, it would form a less suitable conductor for discharging with great suddenness of electric energy. Owing to the fact that the current only penetrates just into the skin of the conductor, there is but little of

* Annalen der Physik und Chemie, No. 108, 1859, p. 499.

the mass of the iron magnetized. Even if these instantaneous discharges are capable of magnetizing iron, ... the electromotive impulses or sudden rushes of electricity do not magnetize the iron, and hence do not find in it any greater self-inductive opposition than they would find in a non-magnetic but otherwise similar conductor. Dr. Lodge's further researches seem to show that there is a real advantage in using iron for lightning conductors over copper, and that its greater specific resistance and higher fusing point enables an iron rod or tape to get rid safely of an amount of electric energy stored up in the dielective which would not be the case if it were copper."*

Fleming describes in full Dr. Lodge's experiments to prove the non-magnetizability of iron by sudden discharges :—

"In the experiments on alternative path, as described by Dr. Lodge, the main result is very briefly summed up by saying that, when a sudden discharge had to pass through a conductor, it was found that iron and copper acted about equally well, and indeed iron sometimes exhibited a little superiority, and that the thickness of the conductor and its ordinary conductivity mattered very little indeed. . . . In the case of enormously rapid oscillations the value of the impulsive impedance varies in simple proportion to the frequency of the oscillations, and depends on the form and size of the circuit, but not at all on its specific resistance, magnetic permeability, or diameter. . . . . For discharges of a million per second and upwards, such as occur in jar discharges and perhaps in lightning, the impedance of all reasonably conducting circuits is the same, and independent of conductivity and permeability, and hardly affected by enormous changes in diameter."†

Turning now to the observations of Hertz, we find it stated that the material, the resistance, and the diameter of the wire of the micrometer circuit employed by him, have very little influence on the result. The rate of propagation of an electrical disturbance along a conductor depends mainly on its capacity and coefficient of self-induction, and only to a small extent on its resistance. Hertz concludes that, owing to the great rapidity of the alternations, the magnetism of the iron is unable to follow them, and therefore has no effect on the self-induction. When a portion of the micrometer circuit employed by Hertz was surrounded by an iron tube, or replaced by an iron wire, no perceptible effect was obtained, and thus the result was apparently confirmed that the magnetism of the iron is unable to follow such rapid oscillations, and therefore exerts no appreciable effect. The velocity of propagation in a wire has a definite value independent of its dimensions and material. Even iron wires offer no exception to this, showing

* Fleming, Induction of Electric Currents, p. 398. † Ibid, p. 411.

that the magnetic susceptibility of iron does not play any part in the case of such rapid motions.*

Although the impulsive impedance is apparently not affected by the magnetic character of the wire, experiments lead me to believe that discharges of the quick period of a Leyden jar are affected very appreciably by the magnetic nature of iron, steel, and nickel conductors. This effect is so great that it dampens the electrical oscillations, and makes it difficult to determine whether the time of oscillation is also affected by the permeability of the conductor.

The apparatus employed was similar to that described in the investigation of electrical oscillations with an air condenser.† Certain important modifications, however, were made. The plane mirror which was used in the former research was replaced by a concave mirror of ten feet focus and three and a half inches in radius. This mirror was mounted upon the end of the armature shaft of a one-half horse power electric motor.

The discharging apparatus consisted of a sharp cutting tool, insulated, and mounted on the edge of the rotating disk bearing the mirror. It was metallically connected with a grooved ring of brass mounted upon the shaft and insulated from it by hard rubber. Around this was wound a copper wire, one end of which was connected with the discharging wire, and the other drawn taut by a rubber band. The electrical discharge was thrown on to the circuit by thrusting forward a lever which brought a solid hinged frame containing a strip of soft type-metal into contact with the rapidly revolving steel-cutting tool. An electrical contact was thus insured by the tool cutting a groove in the strip of type-metal. In order to avoid a spark at the contact, the type-metal was thickly covered with a wax of peculiar composition. The only spark that occurred, therefore, was the one the oscillations of which I desired to study. At each trial the type-metal was moved so as to expose a new cutting surface. The type-metal was insulated from the rest of the apparatus, but connected with the outer coating of the Leyden jar; first both terminals of the Holtz machine were thrown off, and immediately after the cutting tool, ploughing its way through the type-metal, placed the outer coating of the Leyden jar in circuit with one of the two parallel wires leading to the terminals of the spark. The other wire was permanently in connection with the inner coating of the jar.

* "Ersetzen wir den bisherigen Kupferdraht durch einen dickeren oder dünneren Kupferdraht oder durch einen Draht aus anderem Metall, so behalten die Knotenpunkte ihre Lager bei. Die Fortplanzungsgeschwindigkeit in allen solchen Drähten ist daher gleich, und wir sind berechtigt, von derselben als einer bestimmten Geschwindigkeit zu reden. Auch Eisendrähte machen keine Ausnahme von der allgemeinen Regel. die Magnetisirbarkeit des Eisens kommt also bei so schmalen Bewegungen nicht in Betracht."—Ann. der Physik und Chemie, No. 34, 1888, p. 558.

† Proceedings of Am. Acad. of Arts and Sci., vol. xxv, p. 109.

Beside the short lead wires above described, the discharging circuit consisted of the two parallel wires 30 cm. apart and 510 cm. long. These were the only portions of the apparatus changed during the experiment, and they were replaced by wires of different material and of different size. The other conditions—length of spark, lead wires, and the copper cross wire connecting the outer end of the long parallel wires—remained undisturbed throughout the experiment.

The Leyden jar was charged each time as nearly as possible to the same potential, judging by the number of turns given the Holtz machine. It is unfortunate that no more accurate means of measuring it were at hand, although the different negatives showed but slight variation. The capacity of the jar to alternations of this period was 5060 electrostatic units.

I describe the discharging portion of the apparatus minutely, for the success of an investigation of this nature depends upon the suppression of all sparks save that which one wishes to observe; and the method surely and completely accomplished this. The photograph of the spark could thus be made to fall very accurately on the sensitive plate. When one considers that the image of the spark was flying through the air on a circle of a radius of ten feet with a velocity of a mile a second, it will be seen that an extremely small deviation in the point of contact between the cutting tool and the type-metal would have thrown the image entirely off the sensitive plate. A singular phenomenon was noticed in this connection. When a comparatively low potential was used, such as that afforded by the air condenser used in our previous investigation, the cutting tool ploughed two or three millimeters along the surface of the type-metal before a spark passed at the point in the circuit where it was desired. With higher potentials this phenomenon was also observed, but the extent of cutting was diminished.

It is possible that the insulating wax may have melted under the sudden blow of the cutting tool, and, flowing around it, prevented instant contact. This seems to us improbable, for a deep and clear-cut groove was made in the soft type-metal. Great attention was paid to the solid structure of this contact apparatus. It was entirely separate from the support of the revolving parts, and was perfectly steady.

The other end of the armature shaft was lengthened into a cylindrical chronograph, similar to that described in the article already cited, and its performance left nothing to be desired. A small Ruhmkorf coil, excited by two storage cells, and interrupted by a seconds pendulum, gave a record of the speed of the mirror. The stylus which drew the spiral turns on the barrel of the chronograph was drawn along the barrel by

means of a small heavily loaded carriage, which, on being released at the moment the lever arm threw the type-metal in contact with the cutting tool, descended an inclined plane of adjustable height.

A small Töpler-Holtz machine charged a large Leyden jar, and it was found to work admirably in all states of the weather. The apparatus which I have thus described was the result of the experience of the previous year, and worked for months without failure; and the taking of photographs of the oscillatory discharge by it became a mere matter of routine.

The following cases were tried:

(1.) When the long parallel wires were of copper (diameter ·087 cm.), the number of double oscillations visible on the negatives averaged quite uniformly 9 or 9·5.

(2.) When the wires were of German silver (diameter ·061 cm.), three oscillations were visible.

(3.) But when an annealed iron wire (diameter ·087 cm.) was substituted, only the first return oscillation was distinctly visible, with occasionally a trace of the first duplicate discharge.

(4.) On substituting fine copper wire (diameter ·027 cm.), five complete oscillations were quite uniformly visible.

(5.) Fine German silver wire (·029 cm.), nickel wire (·019 cm.),* soft iron (·027 cm.), and piano steel wire (·027 cm.), gave but faintly the first return discharge after the pilot spark.

The pilot sparks were in all cases strong.

The single return discharge through the iron wire did not admit of measurement sufficiently accurate to furnish any basis for calculation of its self-induction. The time did not apparently differ, if at all, by more than fourteen or fifteen per cent. Some general reasoning based upon the number of oscillations may be of interest. It must be acknowledged, however, that this reasoning is open to criticism, although it affords the most plausible explanation. The phenomenon itself is not a doubtful one.

The time of a double oscillation for the large-sized copper wire was ·0000020 sec.; for the small copper wire, ·0000021 sec. The others as far as could be determined did not differ much from these values, and for this purpose either is sufficiently accurate. Denote by R′ the ohmic resistance of the parallel wires to alternating currents of this periodicity; by R, the resistance to steady currents.

$$p=\frac{2\pi}{t}=3{,}000{,}000 \text{ (pratically)}.$$

Taking the cases up in order:

* Obtained by the kindness of Joseph Wharton, Esq., of Philadelphia.

(1.) Large copper wire,

$$R=0{\cdot}285\times10^9$$

and substituting in Lord Rayleigh's formula, $R'=\sqrt{\frac{1}{2}pl\mu R}$,

$$R'=0{\cdot}66\times10^9.$$

(2.) Large German silver wire,

$$R=9{\cdot}2\times10^9,$$

and substituting in the series

$$R'=R\left\{1+\frac{1}{12}\frac{p^2l^2\mu^2}{R^2}-\frac{1}{180}\frac{p^4l^4\mu^4}{R^4}+\ldots\right\},$$

$$R'=9{\cdot}2\times10^9.$$

(3.) Large iron wire,

$$R=2{\cdot}5\times10^9,$$

and if there is a true time lag, as often stated, such as to prevent action of the magnetic property of the iron, and if on this assumption we make $\mu=1$,

$$R'=2{\cdot}78\times10^9$$

(4.) Fine copper,

$$R=3{\cdot}3\times10^9$$

$$R'=3{\cdot}5\times10^9.$$

(5.) Again, as before, call $\mu=1$ in iron, nickel, and steel. The length of these circuits was 7·41 meters, the remainder of the 10·20 meters − 2·79 meters—being of copper wire of $R'=0{\cdot}94$.

The value of R' in the separate cases, including in each the resistance 0·94 of the copper portion, was as follows:

Soft iron	$15{\cdot}0\times10^9$
Piano steel	$20{\cdot}7\times10^9$
Nickel	$30{\cdot}6\times10^9$
German silver	$23{\cdot}0\times10^9$

The ratio of the strengths of successive discharges during the oscillation is given by the function $\varepsilon^{\frac{rT}{2L}}$, where r is the ohmic resistance, T the time of a double oscillation, and L the self-induction. The ratio of one discharge to the nth one after it is $\varepsilon^{n\frac{rT}{2L}}$. If we assume—and it is a large assumption, but one which perhaps the result will in some measure justify—that the ratio of the strength of the first to the strength of the last visible discharge is more or less a constant, we may make use of the above data. Denote $\frac{T}{2L}$ by A, and call the unknown

resistance of the short connecting lead wires and of the spark x. Then will $r = R' + x$, and n will be the number of complete oscillations visible.

Take cases (1) and (2), large copper and large German silver wires :—

$$\varepsilon^{n_1(R'_1+x)A} = \varepsilon^{n_2(R'_2+x)A};$$
$$n_1(R'_1+x) = n_2(R'_2+x);$$
$$9{\cdot}5\ (0{\cdot}66+x) = 3\ (9{\cdot}2+x);$$
$$x = 3{\cdot}4 \text{ ohms.}$$

Taking cases (1) and (4) similarly,

$$n_1(R'_1+x) = n_4(R'_4+x);$$
$$9{\cdot}5\ (0{\cdot}66+x) = 5\ (3{\cdot}5+x);$$
$$x = 2{\cdot}6 \text{ ohms.}$$

Experiments with other copper wires having R′ equal to 3·4 and 1·27 give 5 and 8 for the values of n respectively, or

$$x = 2{\cdot}4 \text{ ohms.}$$

The resistance (R′) of the lead wires forming part of x was 0·8 ohm, leaving as a possible value for the resistance of the spark about 2 ohms.

If, taking this value of x, we calculate the value of R′ necessary to damp out the oscillation in one complete double discharge in the case of the large iron wire, we shall have

$$9{\cdot}5\ (0{\cdot}66\times 3) = 1\ (R'+3);$$
$$R' = 30 \text{ ohms.}$$

But neglecting the magnetic property of the iron, its calculated resistance to alternating currents of this periodicity was R′ = 2·78 ohms. This is obviously inadequate, and would point to the conclusion that the oscillation is not, as sometimes stated, too rapid to admit of the magnetic action of the iron.

If we substitute this value R′ = 30 in the equation

$$R' = \sqrt{\tfrac{1}{2}\, pl\, \mu R},$$

we have for the resulting value of the magnetic permeability $\mu = 230$. This lies between the limits $\mu = 103$ and $\mu = 1110$, found by taking the number of oscillations one and a half and one-half respectively for the case of the iron wire.

It should be noticed that this estimate of μ necessitates assuming that T and L remain the same within broad limits. Measurements of the single oscillation on the negatives show that this is near enough the case. Part of the more rapid decay of the oscillation in the iron may be well ascribed to the dissipation of energy by hysteresis. While we cannot place much reliance upon an estimate of its value in such a case,—its percentage effect probably increasing rapidly with the decay

of the spark,—it is not difficult to show that its influence may be very great.

There still remains the fact, not generally recognized, that, in Leyden jar discharges through iron wires, the magnetic property of the iron has time very materially to modify the character of the spark.

We give an example of the measurement of the half-oscillation which was the only one visible on the photograph of the discharge over iron wires, all the others having been dampened or extinguished by the iron, in comparison with the measurement of the similar half-oscillation on copper wires of the same diameter as the iron wires. The number of oscillations on the copper wires was eight.

The total duration of the discharge on iron wires was only three millionths of a second, while that on similar copper wire was three hundred-thousandths of a second. A steel wire gave the same results as the annealed iron wires.

Comparative lengths of first half-oscillation in millimeters.

Fine iron wire.	Fine copper wire.
·23	·19
·21	·20
·19	·20
—	—
·21	·19
Large iron wire.	**Large copper wire.**
·20	·17
·20	·18
·19	·20
—	—
·19	·18

I wish to express my deep obligations to my assistant, Mr. W. C. Sabine, for his valuable suggestions and for his skill in the mechanical details of this investigation.

Conclusions.

1. The magnetic permeability of iron wires exercises an important influence upon the decay of electrical oscillations of high frequency. This influence is so great that the oscillations may be reduced to a half-oscillation on a circuit of suitable self-induction and capacity for producing them.

2. It is probable that the time of oscillation on iron wires may be changed. Since we have been able to obtain only a half-oscillation on iron wires, we have not been able to state this law definitely.

3. Currents of high frequency, such as are produced in Leyden jar discharges, therefore magnetize the iron.

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ART. XXII.—*Genesis of Iron-ores by Isomorphous and Pseudomorphous Replacement of Limestone, etc.;* by JAMES P. KIMBALL.

IT is the object of the present memoir briefly to develop the following proposition, namely, that well recognized products of epigenesis, like siderite and ferro-calcite, in their several forms and wide distribution especially on a petrographic scale, are as a rule also products of direct pseudomorphous replacement of isomorphous calcic carbonate, like limestone, calcite, calc-sinter, calcareous sediments, calc-schutt, etc. This proposition is not new. But some of the conditions remain unsettled. So also some of the deductions which have been thought, or may seem, to follow. These it is my purpose briefly to discuss.

Contingent to this proposition, it follows that secondary or indirect replacement of calcic carbonate by ferric hydrate is wrought through alteration of pseudomorphous siderite or ferro-calcite, and also, through progressive alteration, by ferric oxide and even magnetic oxide. Hence proximate derivation from siderite of many occurrences of iron-ores which nevertheless are ultimate products of indirect or progressive pseudomorphism of calcic carbonate—itself often a product of epigenesis from basic silicates. Such occurrences may therefore be regarded as instances of double pseudomorphism, sometimes on a petrographic scale; that is, pseudomorphism in the first instance by substitution or replacement; in the second instance by alteration.

Again, ferric hydrate apparently directly pseudomorphous after limestone is produced by immediate, perhaps spontaneous, oxidation of ferrous carbonate, resulting from interchange or double decomposition between solutions of this salt or ferrous sulphate and calcic carbonate in place. All these permutations proceed from the same reactions, but differ in results according to atmospheric environment—whether oxidizing or not. The instable salt as first separated, it is scarcely necessary to add, is thrown down from solutions either of ferrous carbonate or ferrous sulphate indifferently, in reaction with dissolved calcic carbonate or other alkaline mono-carbonates. This salt however, it is important early to remark, is the hydrous salt, from which geologists, it seems, are not accustomed to distinguish the anhydrous carbonate which is almost, if not altogether, exclusively its natural form.

Other adventitious occurrences of brown and red ferric oxide well recognized as exotic, that is, neither in original

place, nor vicariously developed, form as such a separate class. These, however, as commonly understood, are products of like reactions between solutions of the same salts in circulating acidulous waters. These products, though sometimes accumulated under favorable conditions of environment and topography, are more commonly dissipated.

But for the instability of hydrous ferrous carbonate, it might be assumed to be transiently produced through reactions of ferrous salts and alkaline mono-carbonates in solution, not far from *loci* of replacement of calcic carbonate by siderite, as the result of transmission of solutions beyond range of reducing or preserving gases. Visible results of precipitation and spontaneous oxidation of this salt into ferric hydrate in these circumstances on the one hand, and direct precipitation of ferric hydrate through oxidation on the other hand, are identical. Hence the two processes in nature can seldom be distinguished.

The general proposition may now be advanced—that deposits of concentrated iron-ores occur far more extensively as pseudomorphous replacements than has hitherto been made to appear; and far more extensively than by original sedimentation of ferric hydrate in hydrographic basins (if indeed important deposits have ever been formed in this way), followed by chemical transmutations so far as essential to their plausible explanation upon theories of such a common genesis. In the present place, suffice it to indicate the impracticability of conceiving of sedimentation of ferriferous material without siliceous alternations; or of great accumulations of non-ferruginous, non-siliceous sediments at all, except in the case of marine limestones. These are preëminently the *habitat* or repositories of massive and stratiform iron-ores of all descriptions. Occurrences of iron-ores in this relation are often, and indeed generally, without transitions. On the other hand, it is easy to conceive, and in numerous instances to prove, effective replacement of limestones of all geologic periods. Among the great number of important stratiform occurrences of iron-ores —that *stratified* ores exist, there seems to me much reason to doubt—that is, homogeneous, non-laminated ores, formed in the natural order of succession of strata between which they are enclosed, and along with which they are commonly assumed, *prima facie*, to be imbedded.

(1.) As deep-sea chemical precipitation of ferric hydrate is out of the question, the circumstance of the presence in limestone of important lenticular deposits of this material or its derivatives, including siderite upon one theory of its genesis, would suffice to prove the invasion of mid-sea or calcareous sediments by at least suspended material from sub-aerial rock-decay. This condition is obviously incompatible with the more important developments of Palæozoic iron-ores, whose relations in

the greater number of instances are with remarkably pure and persistent limestones, comparatively free from intercalations of argillaceous matter, also a residual product of rock-decay, and invariably accompanying ochreous matter in suspension. Again, replacement of limestone naturally progresses from exterior and divisional surfaces. This, as commonly observed, wherever incomplete, has invariably affected superficial or upper parts of formations under gentle dips, and seldom nether parts except under steep dips. Lenticular bodies of iron ores, not purely concretionary, are very rarely if ever found completely enclosed in pure limestone—that is, in any form corresponding to the filling of a hydrographic basin of marine limestone.

Conditions above briefly noticed are well illustrated, as I shall endeavor to show, by the more important developments of iron ores upon horizons of limestones and adjacent transition strata of all geologic periods.

(2.) The geologic importance of the phenomena of displacement of calcium-carbonate by ferrous carbonate was long since indicated by Bischof, mainly, as it appears, on mineralogic or *a priori* grounds.* Pseudomorphous siderite after calcite, occurring in drusy cavities in anamesite, as described by Blum and Sandberger, was attributed to removal of calcium carbonate by carbonated solutions of ferrous carbonate and deposition of this salt in its place. The same result, as well-known, is produced by reaction of solutions of ferrous sulphate, calcium sulphate being removed.

(3.) Pseudomorphic replacement of calcite by ochreous ferric oxyd was observed by Blum to have taken place indirectly, namely, first by substitution of ferrous carbonate followed by alteration of this comparatively unstable compound. As pointed out by Bischof, it seems probable indeed that pseudomorphs of this type are necessarily indirect—never direct.†

(4.) Aside from pseudomorphs by incrustation, pseudomorphous siderite commonly occurs by substitution of anhydrous isomorphous minerals. Pseudomorphism by alteration often succeeds pseudomorphism by substitution. Both processes, as inferred from relative densities, are attended with contraction. In the conversion of siderite into limonite, this, according to Hunt, amounts to nearly twenty per cent.‡ Hence the exhibition of cavities, anfractuosities and dislocations in products of either transformation, as witnessed both on a mineralogic and petrographic scale.

(5.) Whatever be the mode of accumulation of ferrous carbonate in various deposits, it can scarcely fail to be recognized as invariably a secondary product universally resulting from the decomposition of diffused proto-silicates of iron by means

* Bd. II, 1864, p. 154.

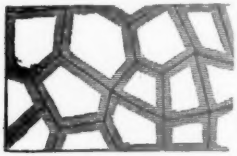
† Chem. Geol., Bd. III, 1866, 871.

‡ This Journal, xxvi, 1883, 202.

of carbonated waters; next in frequency, from solutions of ferrous sulphate in reaction with calcic carbonate; and, lastly, from like reactions with ferrous salts from reduction of ferric silicates.

(6.) The stability of this more or less alterable secondary product in fissures and deep-seated strata in an atmosphere of carbonic anhydride or reducing gases, was also long since pointed out by Bischof and W. B. Rogers, as well as its transformation into ferric hydrate through displacement of such gases by atmospheric air.

(7.) The frequent occurrence of limonite and hematite in limestone and their graduation into beds of this sedimentary material, as well as the presence of similar fossils in both, are facts adduced by Bischof to justify the conclusion that iron-ore deposits of this description have had their origin in replacement of limestone beds.* Yet, as by him remarked, replacement of amorphous limestone by ferric oxide obviously cannot be proved mineralogically as in the case of rare occurrences of incomplete pseudomorphs after calc-spar, like the specimen originally described by Blum. But every geologist has nevertheless observed ultimate replacement of limestone by brown and red ferric oxides, whether direct or indirect, among the more common phenomena of weathering. When as sometimes happens this is all but complete, and the original form of the limestone mass is preserved *in situ*, the replacement is likewise seen to be pseudomorphic—at least in a petrographic sense. Dana has given a good pictorial illustration of this kind in describing an occurrence in the Cone ore-pit at West Stockbridge.† The cut is here reproduced. Replacements of shells and parts of crinoids, still more common, are likewise pseudomorphic in the same limited sense.



The above proposition affords grounds for a ready and complete explanation of the common association of iron ores with limestone as far from accidental. This association would obviously be still more common had all replacements of thin limestone beds been only partially effected, as in replacements of thick limestone, which are necessarily incomplete or relatively superficial. Occurrences of the latter kind justify the conclusion that thin beds of limestone have in fact in numerous instances been wholly or pseudomorphously replaced. Hence frequent occurrences of lenticular beds of siderite and of its derivatives in place of thin limestones, of which no trace may remain except

* Bd. III, 1866, 873.

† This Journal, xiv, 1877, p. 136. See, also, Rep. Tenth Census, xv, 292, 296, 297, 299, 396.

form, and perhaps character of insoluble contents, on the one hand; and local developments of iron-ores, void of anything like regular form, within the compass of a thick limestone formation, and graduating into that material, on the other hand. The latter modes of occurrence (and by inference the former also) are particularly well illustrated by numerous stratiform iron-ore developments in strata of the Carboniferous period. These strata are understood by all to have accumulated under specially favorable conditions of environment for the production of the materials of iron-ores through internal chemical transmutations; and to have since subsisted under equally favorable atmospheric conditions for the preservation of alterable kinds of material produced, like siderite and sphærosiderite.

(8.) The possession of many physiographic characters by stratiform iron-ores in common with deposits *in situ*, formed in the natural order of strata between which they are imbedded, or rather enclosed, has naturally led geologists to seek an explanation of at least Carboniferous iron-ores of this description on theories of direct deposition either chemical or mechanical: that is, according to one theory, in original form of ferrous carbonate; or, according to another theory, as the product of transmutation of ferric hydrate in place into the same compound, through successive deoxidation and carbonating agencies, the potential influence of which in the development of this particular series of strata it may not seem difficult to imagine on grounds of either theory. As to further alteration from weathering action, regulated by circumstances of topography and environment, all are agreed.

The same agencies however may well be believed to have been equally potential in clearly recognized processes resulting in pseudomorphous replacement of limestone by ferrous carbonate, especially in the preliminary work of decomposing diffused clastic ferrous and ferric silicates, dissolving their soluble products, and in the generation and preservation unaltered of anhydrous ferrous carbonate in concrete form however produced.

(9.) While dissolved alkaline mono-carbonates, as well known, readily precipitate instable hydrated ferrous carbonate from solutions of ferrous salts, no artificial method appears to have been proposed for the production at ordinary temperatures of anhydrous ferrous carbonate.

(10.) The generation of this natural compound in the form of siderite and sphærosiderite is sometimes attributed to direct precipitation and concentration of hydrous ferrous carbonate in the presence of reducing gases, or of an atmosphere of carbonic anhydride. This presupposes dehydration at ordinary temperatures by some natural process as yet unexplained.

Upon another theory, commonly entertained as a collateral theory by the same geologists who employ the one just stated, its derivation is also attributed to direct deposition through volatilization of free carbonic acid from aqueous carbonated solution—likewise in atmospheres of hydro-carbon gases and carbonic anhydride.

(11.) No natural occurrence and therefore no mineral species of hydrous ferrous carbonate seems to have been recognized by mineralogists. A moderately instable white, earthy amorphous hydrate said by Massieu to have occurred in the mineral lode of Pontpéon, France,* seems to have possessed the same characteristics as an occurrence beneath an ochreous deposit of a carbonated spring near Laacher-See in the Eifel, but described by Bischof as siderite or the anhydrous salt.† The same locality is famous for exhalations of carbonic acid. Preservation of the artificial product appears to be impracticable except in an atmosphere displaced by carbonic anhydride, or, as easily supposable, by reducing gases.

(12.) Siderite pseudomorphous after crystalline anhydrous calcic carbonate not uncommonly occurs both in hexagonal and trimetric forms, though isomorphous only in the former case. This fact goes far to show that the phenomena of replacement of calcic carbonate by anhydrous ferrous carbonate are not simply those of isomorphism. Yet it is true that in crystalline as well as in amorphous siderite ferrous carbonate is extremely apt to be partially replaced with isomorphous carbonates of lime, magnesia, manganese and zinc. The first three, and sometimes all four, of these carbonates are freely developed even where sparry siderite distinctly occurs as a product of epigenesis, particularly in drusy cavities and fissures in basic rocks inaccessible to atmospheric air.

(13.) The much greater tendency to precipitation of ferric hydrate from aqueous solutions of ferrous carbonate than of the salt itself by dissipation, as assumed, of carbonic acid, is well exhibited by Roth in the case of numerous mineral waters and deposits of mineral springs, as well as the relative and proportional precipitation of alkaline and manganous carbonates.‡

The existence of stable siderite in calcareous sinter points to replacement of calcic carbonate previously deposited. Away from oxidizing atmospheres, anhydrous ferrous carbonate, if ever directly deposited, which there seems much reason to doubt, is probably by reaction of solutions of ferrous salts with these anhydrous carbonates, and at ordinary temperatures in no other way. But as all known reactions of this kind result in hydrous ferrous carbonate from which passage into the anhydrous carbonate at ordinary temperatures is difficult to

* Compt. Rend., lix, 238. † Chem. Geol., Bd. I, 1863, 550.
‡ Chem. Geol., Bd. I. 565, 577.

imagine, the problem still remains.—Whence the production of the anhydrous carbonate?

(14.) In this question one is confronted by the remarkable fact that writers within the field of chemical geology habitually fail to discriminate between the two carbonates either in noting rare occurrences of hydrous carbonate, if such they really be, developed in reactions commonly yielding this extremely alterable or evanescent form; or in tracing epigenesis of comparatively stable anhydrous carbonate, either crystalline or amorphous, from like reactions. On the contrary, it seems to have been assumed that chemical reactions, geologically considered, producing hydrous carbonate, might equally serve, at least eventually, to produce anhydrous carbonate. As in many other unexplained instances of dehydration, conceivable only at ordinary temperatures, this phenomenon has probably been supposed to be an effect of inscrutable operations of time Bischof, for instance, to whom we owe what still stands as the fullest conspectus of this subject, fails to distinguish as such the hydrous carbonate, which as yet appears to be exclusively the product of well understood reactions.

(15.) Now there seems much reason to doubt that anhydrous ferrous carbonate is ever directly deposited from acid solutions of ferrous salts except in circumstances of contact with isolated or solid anhydrous alkaline mono-carbonates, probably at the point of double decomposition, or in the nascent state of the ferrous salt. Such a mode of development, if assumed, must be considered due to the well known isomorphous relations of anhydrous ferrous carbonate and its pseudomorphic tendencies. This explanation appears at least consistent with the phenomena of replacement, both isomorphous and pseudomorphous, of amorphous calcic carbonate; and may perhaps be found adequate to explain most occurrences of crystalline siderite on the theory of its epigenic origin in all cases. Some of these points will now be further considered.

(16.) It is remarkable that although in the earlier volumes of his great work, Bischof was the first, I believe, to point out the importance of replacement of limestone as one mode of genesis of siderite, he assumes in his supplementary volume stratiform developments of this epigenic compound, particularly in Carboniferous series of strata, to have been directly deposited from its carbonated water solution as an effect of volatilization of carbonic acid, and to have been preserved from oxidation by hydro-carbon gases. Yet the constant association in these strata of carbonic acid along with those gases is remarked by Bischof in the same place.* Even by loss of half-combined carbonic acid, however difficult to imagine as taking place in an atmosphere impregnated with the same gas, it is extremely

* Chem. und Phys., Geol. Suppl., Band 1871, p. 64.

doubtful whether the anhydrous salt would be deposited. A no less important difficulty arises as to the *locus* of deposition. If this take place at the surface, the presence of these gases can scarcely be imagined; and if below—conditions are precluded for lenticular accumulations. Beneath the surface conditions exist for deposition by segregation or replacement only.

(17.) In any theory of the genesis of siderite, it becomes necessary first of all to explain occurrences of siderite in lenticular form, as widely distributed: that is, as a product of direct superficial deposition in hydrographic basins; or else of chemical replacement of lenticular beds originally deposited in that manner. Between these alternatives the former seems to me to be quite impracticable.

Lenticular deposits from either chemical or mechanical precipitation are formed exclusively at the surface, that is, in hydrographical basins or bottoms where conditions essential to stability of hydrous ferrous carbonate can not ordinarily be set up, or at least long maintained. Besides, wherever this salt is separated from standing water it must be assumed to pass spontaneously into a higher state of oxidation. Not only does it appear, then, that lenticular developments of ferrous carbonate can not have been superficially deposited, but that this compound can not have been derived from direct precipitation.

(18.) Senft's theory of the genesis of siderite and sphærosiderite seems to have been founded on special occurrences of stratiform and nodular clay-ironstone enclosed in clays and shales. These are explained as epigenic products resulting from saturation of buried argillaceous sediments with acid solutions of ferrous carbonate, supposed to yield the neutral salt upon evaporation; or again by interchange with stronger bases like lime. Spathic carbonates are likewise supposed by Senft to proceed from absorbents like calcareous material, clay or marl.* However applicable may seem parts of this theory to concretionary lenses and nodules of clay-ironstone contained in beds of residual clay and shales, it must be seen to be incompatible with the composition of spathic siderite of considerable purity, that is, when comparatively free from earthy admixtures, as well as with conditions of deposition in the form of lenticular beds. Like other explanations, it rests on the assumption that anhydrous ferrous carbonate may be separated by evaporation as well as by precipitation from acid solutions of ferrous carbonate, a reaction probably true only in a limited sense as above pointed out.

The reaction however incidentally mentioned by Senft, namely, the isolation of ferrous carbonate by interchange of solutions of ferrous salts with stronger bases like lime, is

* Gesteins und Bodenkunde, 1877, 28.

probably the prevailing one in the circumstances cited. For alkaline mono-carbonates, likewise resulting from decomposition of silicates, may safely be assumed to be present partly in undissolved or diffused form wherever ferrous oxide is available, or wherever ferrous salts are displaced from solution.

(19.) While such reactions may be readily believed to take place in fissures, particularly in contact with segregations of calcic carbonate, they can hardly be assumed with Senft also to extensively obtain in clay bottoms of standing water, or beneath peat-bogs and marshes, still less in a manner to result in direct deposition in bedded form from water. In such circumstances not the anhydrous salt but the hydrated ferrous carbonate, if either, would be deposited; this however quickly passing into ferric hydrate. Still more likely, ferric hydrate would be directly deposited from solution through dissipation of free carbonic acid. Yet I am not prepared to deny that from the condition of ferric hydrate however accumulated anhydrous ferrous carbonate may eventually be formed by de-oxidation and by carbonating processes. If so, this could be only after the original deposits are buried deep below superficial sediments and so excluded from atmospheric oxidation.

(20.) Hence, perhaps, the more commonly received metamorphic theory of the genesis of stratiform siderite, generally assumed to be stratified. This theory, based on the assumption of relative origin corresponding to the natural order of enclosing strata, involves, in short, alteration *in situ* of ferric hydrate commingled with vegetable matter originally accumulated in hydrographic basins. This process is also supposed to be excluded from atmospheric air under cover of successive sediments.

(21.) Some of the objections to this theory as a general explanation of the genesis of siderite will appear farther on. Especially will it, as I think, be found to fail to explain the prevailing occurrence of siderite and ferro-calcite in association with limestone, or on horizons of limestone, or in lenticular form otherwise than concretionary.

(22.) On the other hand, a theory of its derivation in such circumstances at least, by isomorphous and pseudomorphous replacement of calcareous material *in situ*, not only seems to fit the greater number of familiar occurrences of siderite, and thus to explain the almost universal association of this secondary product with limestone, and the graduation into each other of these two materials of widely opposite derivation; but to be alone adequate to explain the epigenesis and indeed existence of the anhydrous salt. Where of course limestone has been completely transformed into siderite, and all immediate evidences of their relation have disappeared, it may sometimes be found practicable to identify lenticular developments of siderite

with horizons of limestone by stratigraphic relations. Impracticable though this may be in certain cases, it should not fail to be considered that as the thinner and less persistent limestones are the only ones liable to complete replacement, actual stratigraphic or even inferential identification is not in all cases to be expected.

(23.) Calling attention to the possible application of the theory of the formation of ore-deposits by replacement or substitution, Emmons expresses the possibility that "in the older and more crystalline rocks, where the calcareous beds are of limited extent, metallic deposits in large masses like those of iron, may have so completely replaced the calcareous material that little or no trace of it remains."* Complete ultimate replacement of isolated masses of emerged coral-reef by ferric oxide on the island of Cuba was described by me in 1884. To this example I shall again take occasion to refer.

"The limits of the actually demonstrated application of the theory of the formation of ore deposits," as remarked by Emmons in the paper just quoted, "are being every day extended, not only by studies of new districts, but by more careful and unbiased studies of old districts in which a different method of formation had previously been determined upon."

(24.) Argillaceous shales and other miscellaneous ferriferous sediments commingled with carbonate of lime, originally accumulated, or resulting from decomposition of component basic silicates or left behind from evaporation of circulating waters, may in whole or in part be transformed into clay iron-stone or siderite, containing insoluble residues of the original beds. This process is again one of replacement. Divisional parts or prisms of such beds separated by planes of cleavage and stratification, and by anfractuosities from shrinkage, pass by progressive superficial oxidation into concretionary or nodular limonite. This process has often been described.†

(25.) Diffused ferrous carbonate resulting from replacement of calcic carbonate, also diffused and more or less commingled with clay containing other insoluble residues of sub-aerial decay of basic rocks, may, especially in sediments as yet unindurated, be involved in what may be termed the extra-molecular tendency of fine clays to form concretionary aggregations. Thus it appears that impure ferrous carbonate in nodular form, so frequently imbedded in clays, shales and grits, is probably a product of secular metasomatic interchange and substitution under genetic conditions varying only slightly with circumstances of environment from conditions governing replacement of limestone beds by siderite.

* Trans. Am. Inst. Min. Eng. 1886. Extract p. 7.

† See Hunt, this Jour., xxvi, 1883, pp. 202, 206.

(26.) In the foregoing remarks no discrimination between limestone and dolomite has seemed necessary, nor specific reference to analogous compounds of magnesium in isomorphous relations to those of calcium. Nor, on the other hand, has it seemed important to refer to relations of the same kind subsisting between corresponding compounds of manganese and iron. For the sake of brevity, the same course will generally be followed throughout the present memoir. Yet it will not fail to be considered that epigenesis of compounds of manganese is practically in common with those of iron, and that in fact epigenesis of a given compound of one metal often involves that of a corresponding compound of the other. Quantitatively considered, this according to M. Dieulafait* appears in relative degree to depend less on the distribution of the two metals in the composition of silicates from which epigenesis proceeds, than might be supposed.

(27.) This chemist observed that the heat of combination developed in the production of (hydrous) ferric oxide and (hydrous) ferrous carbonate from ferrous oxide to be respectively 26·6 and 10·0 calories (Fr). In corresponding reactions resulting in the production of manganic oxide (hydrate) and (hydrous) manganous carbonate 21·4 and 13·6 calories were developed.†

When oxygen and carbonic anhydride both in excess come in contact with minerals containing ferrous and manganous oxides, the latter, as may therefore be inferred, will be converted into ferric oxide (hydrate) and manganous oxide (hydrate) and no carbonate will be formed. It is also inferred by Dieulafait that if these gases come in contact with the producing minerals slowly and in quantity insufficient to transform both oxides, the products will be insoluble ferric oxide (hydrate) and soluble (hydrous) manganous carbonate. This serves to explain at least the formation of ferric hydrate comparatively free from manganic hydrate, as well as the separate generation of manganic hydrate comparatively free from ferric hydrate—perhaps in another *locus* of deposition after further transmission of solutions.

Again it is inferred, that as much more heat is developed when ferrous oxide is converted into ferric oxide (hydrate) than when converted into (hydrous) ferrous carbonate, the latter can be formed only in circumstances where atmospheric air is displaced by reducing gases or carbonic anhydride, to the exclusion of oxygen.

* Comptes Rendus, ci, 609, 644.

† The parentheses are mine, the observer ignoring the distinction between hydrous and anhydrous compounds.

ART. XXIII.—*On the Constitution of certain Micas, Vermiculites and Chlorites;* by F. W. CLARKE and E. A. SCHNEIDER.

IN a previous paper upon the constitution of the silicates,* we sought to establish some new lines of attack upon the problem, especially with reference to the mica and chlorite groups. The present communication is to be regarded as a continuation of the same research, and by essentially the same methods; although in some instances the experiments have been less elaborate, when elaborateness seemed to be unnecessary. Throughout the investigation the fundamental hypothesis that the minerals studied are substitution derivatives of normal salts has been kept steadily in view; and, as we believe, it has been amply justified.

Of the so-called vermiculites, two only, jefferisite and kerrite, were considered in our former paper; and these were shown to be trihydrated micas, in which the original alkalies had been replaced by hydrogen. To these examples we now add several others; of which two varieties afford excellent checks upon the earlier work. The two minerals in question are an altered biotite from the zircon mine in Henderson County, N. C., and the protovermiculite from Magnet Cove, Arkansas, described some years ago by Kœnig. The analyses, with itemized water determinations, are as follows:

	Henderson Co. Analysis.	Mol. ratio.	Protovermiculite. Analysis.	Mol. ratio.
SiO_2	38·18	·636	34·03	5·67
TiO_2	1·68	·021	undet.	----
ZrO_2	none	----	----	----
Al_2O_3	14·02	·138	14·49	·142
Fe_2O_3	13·02	·081	7·71	·048
FeO	2·22	·031	0·14	·002
MnO	0·38	·005	0·09	·001
MgO	14·62	·385	20·89	·522
CaO	0·17	·003	1·88	·034
BaO	0·06	----	----	----
K_2O	5·40	·057	----	----
Na_2O	0·48	·008	----	----
H_2O, 105°	3·20	·178	11·23	·624
" 250°–300°	2·52	·140	4·55	·253
" above 300°	4·80	·267	5·41	·301
	100·75		100·42	
H_2O over H_2SO_4	3·20		11·34	

* This Journal, Oct., Nov. and Dec., 1890.

The analysis of protovermiculite agrees with that of König as well as could be expected, but is carried out somewhat more in detail. In its appearance the mineral was dark brown, broadly foliated, much decomposed, and very brittle. Before the blowpipe it exfoliates and fuses easily. The Henderson County mica was also brown, brittle and decomposed, exfoliating when heated and fusing at the edges. Both minerals were examined optically by Mr. Waldemar Lindgren. The protovermiculite he describes as "yellowish, containing in arborescent forms between the plates a great deal of a deep yellow or reddish substance, probably hydroxide of iron. Angle of optical axes larger than usual. Slight pleochroism; thicker plates remain light between crossed nicols." Of the Henderson County mica he says—"contains no titanium mineral. Contains a few grains of a colorless, strongly double-refracting mineral of uncertain nature, possibly zircon. Plates nearly dark between crossed nicols. Angle of optical axes small, but distinctly observed." In the material selected for analysis the impurities noted by Lindgren were so far as possible removed.

The composition of each mineral reduces quite easily, in accordance with the methods followed in our former work, to a mixture of simple isomorphous types. The only uncertainties appear to be in connection with the loosely combined water, which is driven off below 300°. In the Henderson County mica we have the molecules

$$\begin{array}{cccc} \diagup SiO_4{\equiv}MgK & \diagup SiO_4{\equiv}H_3 & \diagup SiO_4{\equiv}MgH & \diagup O \\ Al{-}SiO_4{\equiv}MgH & Al{-}SiO_4{\equiv}H_3 & Fe{-}SiO_4{\equiv}MgH & Fe{-}O{>}Mg \\ \diagdown SiO_4{\equiv}Al & \diagdown SiO_4{\equiv}H_3 & \diagdown SiO_4{\equiv}Fe & \diagdown SiO_4{\equiv}H_3 \end{array}$$

in the ratio $8:1:3\frac{1}{2}:3$. The loosely combined water is in the proper amount to monohydrate the four molecules; but its actual distribution is uncertain. In the subjoined table monohydration is provisionally assumed. In the protovermiculite we have the three molecules

$$\begin{array}{ccc} \diagup SiO_4{\equiv}H_3 & \diagup O & \diagup O \\ Al{-}SiO_4{\equiv}H_3 & Al{-}O{>}Mg & Fe{-}O{>}Mg \\ \diagdown SiO_4{\equiv}H_3 & \diagdown SiO_4{\equiv}H_3 & \diagdown SiO_4{\equiv}Al \end{array}$$

each plus three molecules of water, in the ratio $14:6:9$. As in the case of jefferisite and kerrite, the three molecules of loosely combined water are unlike; two being given off over sulphuric acid, and the third retained rather more tenaciously.

Reducing the original analyses to 100 per cent, uniting all similar oxides to similar type, reckoning FeO as MgO, Na_2O as K_2O, TiO_2 as SiO_2, etc., we get the following comparison between observation and theory:

	Henderson Co.		Protovermiculite.	
	Found.	Calc.	Found.	Calc.
SiO_2	39·70	39·90	34·10	34·18
Al_2O_3	14·12	14·25	14·52	14·78
Fe_2O_3	13·11	13·15	7·72	7·20
MgO	16·32	17·08	22·41	22·79
K_2O	6·17	6·17	----	----
H_2O, essential	4·83	4·87	5·43	5·40
" hydration	5·75	4·58	15·82	15·65
	100·00	100·00	100·00	100·00

These results, taken in connection with our work on jefferisite and kerrite, and with the mica theory upon which all our formulæ are based, are exceedingly suggestive. Kerrite is essentially a trihydrated hydro-phlogopite. Protovermiculite is the same substance, commingled with a tri-hydrated hydro-clintonite, in the ratio 1 : 1 very nearly. Jefferisite is a similar mixture of hydro-biotite and hydro clintonite, also trihydrated, and in the ratio 1 : 1. The Henderson County mica is essentially a biotite, about half way transformed into a vermiculite, and is interesting as a transition product. The hydration of its several admixed molecules is naturally uncertain. At an early date we hope to imitate experimentally the process by which a mica becomes transformed into its corresponding vermiculite.

But although the above-named minerals appear to be very simple in their structure and relationships, a like simplicity does not characterize all of the vermiculites. In some members of the group there seem to be a small admixture of chloritic molecules, and it is even probable that many intermediate stages between mica and chlorite may exist. As bearing upon this question we have a series of vermiculitic minerals from Chester and Delaware Counties, Pennsylvania, some of which have already been studied by Cooke, Gooch, Leeds and others, while some have escaped examination hitherto. To begin with we may consider the hallite, from Nottingham, Chester County, and the vermiculites from Lenni, (not Lerni), Delaware County. The hallite, received through the kindness of Mr. W. W. Jefferis, was dark bluish green, and agreed perfectly with the published descriptions. The Lenni mineral, partly from the collection of the late Isaac Lea, and partly gathered in the field by one of us, is represented by several varieties, which in a large series of specimens, are seen to shade into each other. Three varieties were examined: one, silver white, resembling outwardly an ordinary mica; a second, bronzy brown, like jefferisite; and the third, dark green, similar to clinochlore. All four substances were examined microscopi-

cally by Mr. Lindgren, who found in the hallite some spear-shaped, rhombic, or more rarely hexagonal inclusions of a dark brown mineral, not further identified. His optical notes will be published in an official bulletin, later. Analyses as follows, with itemized water determinations:

	A. Hallite.	B. Lenni 1.	C. Lenni 2.	D. Lenni 3.
SiO_2	35·54	36·72	35·09	34·90
TiO_2	undet.	0·18	0·58	0·10
Al_2O_3	9·74	10·06	12·05	10·60
Fe_2O_3	9·07	5·37	6·67	8·57
Cr_2O_3	----	0·26	0·46	0·23
FeO	0·28	0·12	0·11	0·22
MnO	0·25	0·31	0·27	0·17
NiO	0·16	0·20	0·20	0·19
MgO	30·05	29·40	27·62	28·21
BaO	----	----	trace	----
H_2O, 105°	2·64	6·40	5·70	4·99
" 250°–300°	1·23	2·68	1·98	1·60
" red heat	10·91	8·69	9·22	9·88
	99·87	100·39	99·95	99·66
Loss over H_2SO_4	undet.	6·92	5·84	5·21

In these analyses we at once see that the combined water is mostly in excess of the crystalline water, and that the formulæ deduced must be correspondingly modified. The molecular ratios are as follows:

	A.	B.	C.	D.
SiO_2	·592	·614	·591	·583
R_2O_3	·152	·134	·163	·159
RO	·760	·744	·698	·712
H_2O, fixed	·606	·483	·512	·549
Aq.	·215	·504	·427	·366

In order to learn something as to the distribution of the hydroxyl indicated by these ratios, resort was had to the process of heating in dry, gaseous, hydrochloric acid, as described in our former paper. From this test, however, the brown Lenni vermiculite was omitted, as being intermediate in its character between the white and the green. Each experiment was made at the temperature 383°–412°.

	A.	B.	D.
Hours heated	16½	16	17
R_2O_3 removed	3·42	1·08	1·56
MgO "	8·09	6·30	6·57
Molec. ratio MgOH	·202	·158	·164

Here it is assumed, on the grounds of our former work, that the magnesia rendered soluble by gaseous HCl is present as

MgOH. Representing this by the symbol R′, the three vermiculites give the following empirical formulæ:

Hallite	$R'''_{304}R''_{556}R'_{202}H_{1010}(SiO_4)_{592}O_{436}$?	215 aq.
White Lenni	$R'''_{268}R''_{586}R'_{158}H_{808}(SiO_4)_{614}O_{259}$?	504 aq.
Green "	$R'''_{218}R''_{548}R'_{164}H_{924}(SiO_4)_{583}O_{408}$?	366 aq.

These reduce at once, subject to small uncertainties as to hygroscopic water, to mixtures of molecules of the hydroclintonite and hydro-phlogopite types, with small amounts of chloritic compounds $Mg(SiO_4)_2(MgOH)_6$ and $Mg_2(SiO_4)_2H_4$. Upon this basis the three minerals become:

Hallite	$Al(SiO_4)_3Mg_2H_3$	3 aq.	7 molecules.
	$AlO_2MgSiO_4H_3$		18 "
	$Mg(SiO_4)_2(MgOH)_6$		3 "
	$Mg_2(SiO_4)_2H_4$		2 "
White Lenni	$Al(SiO_4)_3Mg_2H_3$	3 aq.	6 "
	$AlO_2MgSiO_4H_3$		5 "
	$Mg(SiO_4)_2(MgOH)_6$		1 "
Green Lenni	$Al(SiO_4)_3Mg_2H_3$	3 aq.	4 "
	$AlO_2MgSiO_4H_3$		8 "
	$Mg(SiO_4)_2(MgOH)_6$		1 "

The actual ratios observed were slightly more complex, but the foregoing expressions accord well with the analyses. Here, as previously, we may reduce the analyses to typical form and 100 per cent, reckoning Fe_2O_3 as Al_2O_3, etc. The comparison is as follows:

Analyses reduced.

	A (Hallite).	B (White).	D (Green.)
SiO_2	36·93	37·56	36·33
Al_2O_3	16·13	14·92	16·83
MgO	31·58	30·41	29·44
H_2O	11·34	8·86	10·26
Aq.	4·02	9·25	6·84
	100·00	100·00	100·00
MgO in MgOH	8·09	6·30	6·57

Calculated.

	A.	B.	D.
SiO_2	36·47	38·11	36·61
Al_2O_3	15·82	14·25	16·97
MgO	31·75	30·49	29·95
H_2O	11·27	8·92	10·47
Aq.	4·69	8·23	6·00
	100·00	100·00	100·00
MgO in MgOH	8·93	6·10	6·66

When we consider the nature of the vermiculites, as products of alteration, the agreement here shown is fully as close as could be expected. Many well crystallized minerals, fresh and unaltered, are less simply interpreted.

On the 19th of February, 1891, Professor Tschermak read before the Vienna Academy a paper on the chlorite group, in which he referred certain vermiculites to that class of minerals. He also put forth some views concerning the constitution of the chlorites, which, however, we cannot discuss until they have been published in full.* One fundamental molecule, regarded by Tschermak as a constituent of most chlorites, we may adopt for present purposes, under slightly different structural form from his. This is the "amesite substance, $SiAl_2Mg_2H_4O_9$, written by Tschermak $SiAl_2H_2O_7(MgOH)_2$. In default of experimental evidence this may be transformed into $OMg_2Si_4(AlH_2O_2)_2$, when it becomes part of a natural chloritic series parallel with the micas—thus:

Normal orthosilicate	$Al_4(SiO_4)_3$	$Mg_4(SiO_4)_3$
Whence we derive,	Micas.	Chlorites.
	$Al_3(SiO_4)_3R'_3$	$Mg_3(SiO_4)_2R'_2$
	$Al_2(SiO_4)_2R'_6$	$Mg_2(SiO_4)_2R'_4$
	$Al(SiO_4)_2R'_9$	$Mg(SiO_4)_2R'_6$
	$Al{-}O{-}R''$ $\quad SiO_4{=}R'_3$	$O{<}Mg{>}SiO_4{=}R'_3$ $\quad\quad Mg$

In other words, the "amesite substance" in our chlorite series is the basic equivalent of the clintonite molecule among the micas, and is applicable to the solution of certain obscure problems. Some of the vermiculites, as Tschermak suggests, are probably chlorites, and two examples have come under our notice in which this view is partly sustained. Both were originally received from Mr. Jefferis; one from the corundum mine at Newlin, Chester County, Pa., and the other from Middletown, Delaware County, in the same State. The Newlin mineral was dull green, and much resembled culsageeite both outwardly and optically. The Middletown vermiculite was bright golden yellow; strongly exfoliating before the blowpipe and fusible on the edges. It was found upon the farm of Mr. James Painter, whence Mr. Jefferis named it provisionally "Painterite," a name which seems also to have been applied to a peculiar brownish, waxy, feldspathic matrix in which the broad golden laminæ were imbedded. A second sample of it was later collected by one of us. According to

* This paper has appeared in extenso since this was written. We cannot, however, discuss it thoroughly at present.

an optical examination by Mr. Lindgren the matrix of the "painterite" is a mixture of plagioclase, probably labradorite, with serpentine. The "painterite" itself shows hexagonal markings on the surface, and contains, Mr. Lindgren says, inclusions of ferric oxide. Optically he found it to show slight double refraction between crossed nicols, the angle of the optical axes being small but distinct. In the Newlin mineral the axial angle was usually large, being at least 25°. Analysis as follows: A, Newlin. B, Painterite from Jefferis. C, Painterite collected by Schneider. D, matrix of painterite.

	A.	B.	C.	D.
SiO_2	31·23	34·86	33·95	52·47
TiO_2	----	trace	trace	none
Al_2O_3	17·52	11·64	12·52	21·72
Cr_2O_3	0·14	----	----	----
Fe_2O_3	4·70	3·78	4·40	1·23
FeO	1·20	0·20	0·20	0.17
MnO	0·20	----	----	----
NiO	0·33	0·14	0·23	----
MgO	31·36	31·32	30·56	9·26
CaO	----	0·07	none	3·25
K_2O	----	----	----	0·63
Na_2O	----	---	----	5·09
H_2O, 105°	1·08	1·64	1·56	1·14
" 250°–300°	0·40	1·03	0·59	----
" ignition	12·15	15·75	16·46	4·74
	100·31	100·43	100·47	99·70

Upon treating the three vermiculites with gaseous hydrochloric acid at 383°–412°, the following results were obtained:

	A.	B.	C.
Hours heated	8	12½	19
R_2O_3 removed	1·09	·80	·78
MgO "	5·86	8·26	9·56
Molec. ratio MgOH	·146	·207	·239

The molecular ratios are:

	A.	B.	C.
SiO_2	·520	·581	·566
R_2O_3	·202	·138	·150
RO	·808	·789	·770
H_2O	·675	·875	·914
Aq	·080	·148	·119

In these examples the water (Aq) expelled below 300° is so small in amount that it may be left out of consideration. Part of it undoubtedly represents hydrated molecules, which, however, are relatively so few in number that they may be for present purposes disregarded.

From the remaining ratios, writing MgOH as R′, the subjoined empirical formulæ are directly derived:

Newlin		$R''_{1}{}^{404}\ R''_{662}\ R'_{146}\ H_{1204}\ (SiO_4)_{520}\ O_{905}$
"Painterite"	B.	$R''_{1}{}^{276}\ R''_{582}\ R'_{207}\ H_{1543}\ (SiO_4)_{581}\ O_{709}$
"	C.	$R''_{300}\ R''_{531}\ R'_{239}\ H_{1589}\ (SiO_4)_{566}\ O_{763}$

Reduced to structural form these give less satisfactory results than the previously considered vermiculites. The Newlin mineral may be regarded as nearly a hydroclintonite, $AlO_2MgSiO_4H_2$ with an admixture of an amesite-like compound $Mg_2OSiO_4(MgOH)_2$ in the ratio 4:1. In reality the mixture is more complicated, and must contain other molecules. The "painterite" C, is wholly chloritic, containing the amesite molecule $Mg_2OSiO_4(AlH_2O_2)_2$, with the molecules $Mg(SiO_4)_2(MgOH)_4$ and $Mg(SiO_4)_2H_6$, in the ratio 16:4:18. These compare with the actual analyses, reduced to typical form and 100 per cent, thus:

	Newlin.		"Painterite."	
	Found.	Calc.	Found.	Calc.
SiO_2	32·42	31·57	35·03	35·59
Al_2O_3	21·39	21·47	16·22	16·13
MgO	33·57	33·69	31·77	30·84
H_2O	12·62	13·27	16·98	17·44
	100·00	100·00	100·00	100·00
MgO in MgOH ..	6·09	8·42	8·56	9·49

The "Painterite" B reduces less easily, but satisfies all the required conditions. It is like C, but contains other chloritic molecules in somewhat complex ratios. It must be remembered that all these minerals are *mixtures*, and the fact that they are reducible at all to simple expressions is a strong point in favor of the theory adopted for the chlorites and micas in general.

A very interesting example of the way in which the chloritic vermiculites approach the serpentines in composition and character has been furnished us by Mr. G. P. Merrill of the U. S. National Museum. It was found by him at Old Wolf Quarry, Chestnut Hill, Easton, Pa., and is described by him as follows:

"It occurs in the form of bright yellowish green inelastic scales of all sizes up to an inch in diameter, associated with a compact tremolite rock which is here quarried and pulverized for use as a filler in paper manufacture. The character of the rock is greatly varied, but at the quarry opening the prevailing material is tremolite more or less altered into serpentine, the vermiculite, and other secondary products, including calcite in both fibrous and granular forms.

The vermiculite, although occurring in plates of considerable thickness readily separable into thin foliæ, never, so far as observed, shows good crystal outlines. Optically it is biaxial

and negative, though the axial angle is small, basal plates in the thin section showing a black cross which scarcely opens at all during the revolution of the stage. Cleavage plates a millimeter or more in thickness show plainly the biaxial character, though the figure is somewhat distorted. Dispersion $\rho < v$.

The surface of the plates is at times plainly marked by sharp lines crossing at angles of 60° and 120° and along which the mineral frequently separates readily. Before the blowpipe the mineral exfoliates and fuses readily on the edges to a thin glass."

According to Mr. Merrill this mineral is sometimes seen in cabinets labelled "talc;" and indeed in its appearance it resembles both talc and serpentine. Upon analysis the following results were obtained, the percentage of K_2O representing two identical determinations.

	Analysis.	Molec. ratios.
SiO_2	43·71	·728
Al_2O_3	3·59	·035
Fe_2O_3	0·90	·006
MgO	38·58	·964
K_2O	2·22	·023
Na_2O	0·13	·002
H_2O, 105°	0·46	----
" 250°–300°	0·09	----
" ignition	10·70	·594
	100·38	

Treated with dry, gaseous HCl at 383°–412° for 16½ hours, 4·36 per cent of magnesia became soluble, corresponding in molecular ratio to 109 mol. MgOH. Hence the mineral, although resembling serpentine in general composition, differs from the latter in its proportion of this molecular group.

Upon treatment with aqueous HCl of sp. gr. 1·12, a small portion remained undecomposed. Ten grams of the mineral were therefore digested with the acid for three days on the water-bath, and the residue was afterwards boiled out with a solution of sodium carbonate to remove liberated silica. The remaining residue, amounting to 3·10 per cent of the original material, was then analyzed separately, and found to contain:

SiO_2	64·53
Al_2O_3, Fe_2O_3	2·03
MgO	33·04
	99·60

All the potash went into solution; whence it seems probable that no muscovite was present. The ratios of the insoluble residue agree very closely with those of talc, and we may there-

fore assume that mineral to be present as an impurity. Deducting from the molecular ratios given above the quantity of talc indicated by experiment we get for the empirical formula of the mineral the expression

$$Al_{82}K_{50}Mg_{938}H_{1170}(SiO_4)_{695}O_{281},$$

which becomes, if the excess of oxygen is regarded as hydroxyl, with $(MgOH)_{109}$ as observed,

$$Mg_{829}K_{50}H_{889}(MgOH)_{109}(AlH_2O_2)_{82}(OH)_9.$$

The small excess of hydroxyl is probably due to undistributed errors of analysis, and may be added to the MgOH, bringing the latter to 118, and reducing the Mg to 820. Then, generalizing, by uniting all the univalent groups and atoms we get as an ultimate formula

$$Mg_{820}(SiO_4)_{695}R'_{1139},$$

which equals, almost exactly,

$$125\ Mg_3(SiO_4)_2R'_2 + 223\ Mg_2(SiO_4)_2R'_4,$$

a result in accordance with our serpentine-chlorite theory. The distribution of the several components of R′ is, however, not clear, and remains to be ascertained. No other discussion of the analysis appears to give as satisfactory results as this, and we have tried several methods of reduction, representing various hypotheses.

One other mineral examined during this investigation remains to be noticed; a pale yellowish-green mica collected by Mr. G. P. Merrill at a granite quarry in Auburn, Me., near where the Maine Central railroad crosses the Androscoggin river. It occurs in direct contact with ordinary, broadly foliated muscovite, sometimes forming marginal growths about the plates of the latter mineral, like lepidolite. Analysis gave:

SiO_2	46·54
Al_2O_3	34·96
Fe_2O_3	1·59
MgO	0·32
K_2O	10·38
Na_2O	0·41
F	none
H_2O, 105°	0·71
" ignition	4·72
	99·63

This is the composition of muscovite, which the mica undoubtedly is. The case is interesting, however, as showing a secondary growth of muscovite on muscovite, with a marked difference in outward appearance between the two formations.

Laboratory U. S. Geological Survey, Washington, D. C., April 27, 1891.

ART. XXIV.—*A Further Note on the Age of the Orange Sands;* by R. D. SALISBURY.

IN a recent number of this Journal, President Chamberlin and the writer set forth what seemed to us sufficient reasons for believing the whole of the Orange Sand series of sands and gravels to be of Pre-pleistocene age. The arguments there adduced we still believe to be sufficient to warrant the conclusions drawn from them.

Since that article appeared, some new facts have come to our knowledge which afford new and more direct proof of the correctness of the position then taken. Until this season's work in the field began, it was not known to us that the Orange Sand gravels reached so far north as the southern border of the glacial drift. They had been searched for along the southern border of the drift north of the area where they are best known, in the hope that they might be found beneath the glacial deposits, but this search had been fruitless, so far as the particular question at issue is concerned.

During the early part of this season's field-work, the writer spent some time in the region between the Mississippi and Illinois rivers above the point of their junction. In this region, in the counties of Calhoun, Pike, Adams and Hancock, the Orange Sand gravels were found to obtain a considerable development. These counties are well north of the southern limit of the glacial drift, and the gravel is uniformly found to occupy a position beneath it. Among other places, this relationship is well shown near Bloomfield, Adams county, where till may be seen resting directly on the brown flint gravels. Here, as at several other localities, the gravel is cemented by iron oxide into a firm conglomerate, though at other points but a few rods away, the gravel is but partially or not at all cemented. It will be remembered that this habit of being firmly cemented at one point, and nearly or altogether free from cement at another, is one of the prominent characteristics of the gravel farther south.

But the Pre-pleistocene (presumably Tertiary) series of the counties named is not limited to the brown flint or "Orange" gravels. Accompanying these, there are very considerable beds of sand, essentially like those accompanying the corresponding gravels to the south. These are best exposed, so far as the writer's knowledge goes, a short distance south of Liberty, Adams county, but they have a considerable development in various parts of this county. At the above locality, till may be seen resting on the sand.

Apart from the obvious proof of the preglacial age of these gravels and sands afforded by the superposition of the drift upon them, the character of the till affords a further proof of the same thing. If the sands and gravels occupied the region before the ice invasion, they should have made their contribution to the drift. This they have done, and so generously that at many points and over considerable areas the character of the drift has been in very large measure determined by this contribution.

To the arguments adduced in the article referred to above for the Pre-pleistocene reference of the Orange Sand gravels and sands, must now be added the further arguments of (1) superposition of the earlier glacial drift upon them, and (2) the contribution of these sands and gravels to this drift.

Subsequent to the writer's determination of the existence of Pre-pleistocene material in the region indicated, reference to the reports of the Illinois Geological Survey revealed the fact that in the reports on Pike and Hancock counties, the Illinois geologists had made note of the fact that ferruginous flint gravels occur beneath the drift in these counties, and that they had further correlated them with the gravels in the southern part of the state. To them, therefore, belongs the credit of the first recognition of these gravels, as wholly distinct from the drift.*

ART. XXV.—*Note on the Causes of the Variations of the Magnetic Needle;* by Professor FRANK H. BIGELOW.

IN May, 1890, I published in Bulletin No. 18 of the U. S Scientific Expedition to West Africa, a preliminary statement of a new theory of terrestrial magnetism which had been conceived in order to account for the observed variations of the free magnetic needle. Since that time my efforts have been directed towards obtaining a clear conception of the mode of action of the forces whose relations were indicated in the Bulletin, and I am now prepared to add a note as a further preliminary statement of the progress made in this study.

On re-examination of the mode of analysis already published, I find that the main conception is not to be modified and that the successive steps are correct. When making an attempt to reduce the observations by means of this treatment, namely, the combination of current functions by the use of harmonics, it was evident that a very complex system of computation

* I am unable at this writing to refer to the Illinois reports, and therefore cannot cite the exact references to the statements therein made. R. D. S.

would be required. My endeavor was, therefore, to simplify the fundamental treatment so as to secure not only a sound theory, but also a working process for handling the observations. To do this two distinct sets of trial computations were made, first by the theory of moments about the rectangular axes whose origin was in the spherical surface passing through the north end of the needle, concentric with the surface of the earth, and forming equations whose solution would give the required constants of the phenomenon. This also failed to be sufficiently simple and direct to show the action in its general relations. The second attempt was an empirical one, for the time abandoning theory, and building up from the simultaneous observations in various parts of the earth such an exhibition of facts as would display the real nature of the laws behind them. This trial has been successful far beyond anticipation, and that too in a simple and practical form. The theory is at best complicated, as it depends upon the laws of magnetic induction in their most complex conditions, but it unifies and classifies harmoniously all the visible motions of the needle.

My method and result are, briefly, as follows: The month of June, 1883, was selected because of the material collected in the publications of the International Polar Commission applicable simultaneously over a large area of the earth, also because the north polar stations were at that time exposed to sunlight throughout the twenty-four hours. The stations used were: Point Barrow, Fort Rae, Kiugua Fjord, Jan Mayen, Bossekop, Sodankylä, Pawlowsk, Wilhelmshaven, Vienna, Tiflis, Za-Ki-Wei, Cape Horn, South Georgien. The monthly means for each hour local time of the horizontal and vertical forces and the declination were reduced to the coördinates, x positive to the north in the mean magnetic meridian of the month, y positive to the west, z positive inwards along the normal, the plane xy being the horizon at the surface of the earth or through the north end of the needle. The differences between the mean and the hourly values, namely ΔH, ΔD, ΔZ, were plotted on paper, smoothed out, the resulting values dx, dy, dz, combined to show the total deflecting force at the station with its magnetic azimuth and altitude, this form of azimuth being finally transformed into north geographical azimuth. My idea was that the needle floating freely in a magnetic line indicated simply its direction, and that the deflections were produced by a component coming to it from space, the motive being to discover the condition of such components over the earth at the same time. Next, a large model was constructed on which these component forces were represented in direction and magnitude. By assigning

certain meridians for the hours, and supposing the permanent pole to take up its position from one meridian to another, there was finally collected upon these meridians representing a series of local hour angles, now referred to the sun as if the earth had ceased to rotate on its axis, an exhibition of what exists over the globe at the same instant of time.

The result is most interesting and gratifying, but I can only indicate now what could be elaborated by a mass of computations. It is difficult to convey any view of the complicated system of lines of force produced by inserting a magnetized or polarized sphere in a field of force, supposing the sphere at rest; if it rotates it is much more troublesome. These references, however, may be cited: Sir W. Thomson in § xxxii, p. 486, Papers on Electrostatics and Magnetism, illustrates some of the forms produced in the case of symmetry, that is, the axis of polarization being parallel to the field; in article 434, Vol. II, Maxwell's Electricity and Magnetism a similar illustration is found; in article 436 of the same is given an example of the sphere being placed at an angle to the field. The mathematical treatment of these cases, when once the constants involved are known, leads to certain typical lines of force entering the sphere at definite angles corresponding to the latitude of the point. Furthermore when the sphere is rotated the whole system recedes through an angle depending on the constants, as indicated in the Bulletin. My model gives the angles and directions corresponding to such a system, if we take the *radiant sunlight as the uniform field of force, directed positive towards the sun.* The entering and emerging forces are on the respective sides of the earth, and the whole system is receding by about twenty-three degrees. The peculiar form of the polar station lines and the inclination of their planes of action to the meridians is well displayed. The stations all over the world bear the same testimony. The action of the coronal field is entirely similar but not strong enough to appear on the model. The separation of the two fields is merely a question of close computation.

There remains one more important point. The positive direction of the earth's permanent magnetism is from the north towards the south side of the ecliptic y, the uniform field is positive towards the sun z, the motion of the earth in its orbit x, is perpendicular to the field. If these are taken as the usual rectangular x, y, z, they form a consistent positive or right-handed cyclic system. In a word, the permanent magnetic condition of the earth may be principally due to the orbital motion of the earth through the radiant field of sunlight. The rotation of the earth on its axis causes a modification of the direction of the axis of polarization, by diminishing

the angle between the two axes, and as the result of the annual motion may cause it to rotate in a secular period about the axis of figure, or if the magnetization has already become set in the body of the earth, may cause a succession of secular waves to sweep over it from east to west, as is shown to be the case in the history of the agonic lines and the long period deflections of the needle.

This surprising identification of magnetic and light action of the radiations of the sun in direction will be recognized as harmonizing with the conclusions arrived at by Maxwell and Hertz in their investigations. If light is to be studied as a magnetic phenomenon it adds a large field to the work allotted to meteorology. Furthermore, several important physical constants relating to the cosmical action of the sun and the earth, and also the implied nature of the sun and the earth as physical bodies are becoming accessible. Attention is directed to the fact that such a force acting towards the center of the sun, being cosmical or universal, is of the kind required to account for the outstanding motion in the perihelion of Mercury, not included in the development or the law of gravitation or its positive side. My next step is to form the necessary equations of condition and solve them for the constants involved in the magnetic observations.

Washington, D. C., July 31, 1891.

SCIENTIFIC INTELLIGENCE.

I. Chemistry.

1. *On Boron tri-iodide.*—According to Moissan, boron tri-iodide can be obtained in three ways : either (1) by passing boron chloride and hydrogen iodide through a red hot porcelain tube, (2) by acting with iodine upon boron directly at 700°—800°, or (3) and most conveniently by acting upon amorphous boron, previously dried in a current of hydrogen at 200°, with dry hydrogen iodide gas, the boron being heated in a combustion tube to a temperature near that of the softening of the glass. In this way purple colored scales are obtained containing some free iodine ; from which they may be freed by solution in carbon disulphide agitation with mercury, and evaporation of the solvent. The boron tri-iodide thus obtained is colorless but becomes colored on exposure to light. It is very hygroscopic, fuses at 43°, boils at 210°, burns in the air at a red heat, has at 50° the approximate density of 3·3 and is easily soluble in carbon disulphide, carbon tetrachloride and benzene. By water it is decomposed into boric and hydriodic acids, and it reacts with phosphorus, silver fluoride and magnesium (at 500°) with combustion; though not with

aluminum, sodium or silver. With alcohol and ether it reacts, yielding ethyl iodide and ortho-boric acid in the former case and ethyl iodide and ethyl ortho-borate in the latter.—*C. R.*, cxii, 717; *Ber. Berl. Chem. Ges.*, xxiv, (Ref.) 387, May, 1891.

G. F. B.

2. *On Hydrazine hydrate and the compounds of Diammonium with the Halogens.*—The researches of CURTIUS and SCHULZ have shown that hydrazine hydrate $N_2H_4 . H_2O$, prepared by distilling the sulphate with potassium hydrate, is a liquid boiling at 118·5° under 739·5 mm. pressure and having at 21° the specific gravity 1·0305. Its molecular mass at 100° in vacuo is 50, corresponding to the formula $N_2H_4 . H_2O$. At 170° under the ordinary pressure, the hydrate is completely dissociated into diamide and water. At higher temperatures the molecular mass diminishes markedly not reaching 50 again at ordinary pressures even at 300° to 400°. In a lead bath, however, numbers approaching 100 were obtained. Hydrazine hydrate in aqueous solution gave approximately the molecular mass 68, corresponding to the composition $N_2H_4 . (H_2O)_2$. Comparing this hydrate with ammonia, as to its action on indicators, this action was shown to be as sharp in all cases except that of phenol-phthalein. When aqueous solutions of hydrazine are neutralized with a haloid acid, and evaporated first on the water-bath, then over potassium hydrate, halogen-diammonium salts are formed, by preference with two equivalents of acid. The bromide and iodide with one equivalent of acid are formed when the free halogen is made to act on an alcoholic solution of hydrazine, a portion of the hydrazine being decomposed. The bi-acid salts crystallize in the regular system, are soluble in water, almost insoluble in alcohol. The mon-acid salts are easily soluble in water and warm alcohol. Tri-hydrazine di-iodhydrate $N_6H_{12} . (HI)_2$ is formed when iodine is added to an alcoholic solution of hydrazine so long as crystals appear. As to the molecular mass of the halogen diammonium compounds in aqueous solution, it is found to be with the mono-halogenides, the difluoride and the sulphate equal to one-half, with the di-halogenides generally equal to one-fourth and with the tri-hydrazine di-iodhydrate equal to one-fifth the simplest formula.—*J. pr. Ch.*, xlii, 521; *Ber. Berl. Chem. Ges.*, xxiv, (Ref.) 256, Apr. 1891.

G. F. B.

3. *On the Synthesis of Indigo-carmine.*—HEYMANN has succeeded in effecting the synthesis of indigo-carmine, the disulpho-acid of indigo, by acting upon phenyl-glycocoll with fuming sulphuric acid. If, for example, phenyl-glycocoll be mixed in a test tube with ten to twenty times its mass of fuming sulphuric acid containing 20 to 25 per cent of sulphuric oxide, and gently warmed, it dissolves with a yellow color, evolving sulphurous oxide gas. On pouring the solution upon ice, it rapidly assumes the greenish blue color of indigo-carmine. For its production, the following method gives the best results: One part of phenyl-glycocoll is mixed with 10 to 20 parts of sand and then intro-

duced into 20 times its mass of fuming sulphuric acid, warmed to 20° or 25°, containing 80 per cent sulphuric oxide; the temperature not being allowed to rise above 30°. The glycocoll goes easily into solution with a yellow color which at once with evolution of sulphurous oxide passes into the deep blue color of the indigo-solution. To remove the concentrated acid, the mass is diluted with sulphuric acid of 66° B. The coloring matter is isolated by farther dilution with ice and the addition of salt. As so prepared the product is completely pure indigo-carmine. The colors obtained in dyeing with it far exceed in brilliancy those obtained from the best varieties of commercial indigo. Its identity with the natural product was established by means of its chemical reactions, by dyeing tests and by spectroscopic examination. The yield is about 60 per cent of the glycocoll taken.—*Ber. Berl. Chem. Ges.*, xxiv, 1476, May, 1891. G. F. B.

4. *Leçons sur les Métaux*, professées à la Faculté des Sciences de Paris. Par ALFRED DITTE, Professeur de Chimie à la Faculté. Premier Fascicule. 4to, pp. 44, lviii, 621. Paris, 1891. (Vve Ch. Dunod.)—To judge from the part of Professor Ditte's book now before us, the complete work will be a valuable addition to chemical literature. It is written largely from the standpoint of energy. In his preface the author says: "The principles of Thermo-chemistry and the consequences which flow from them, teach us not only to explain reactions, but also frequently to foresee them and to discover in advance what phenomena will be produced when two or more substances are put together under determined conditions. On the other hand when two reactions are simultaneously possible the laws of dissociation enable us to define rigorously the conditions of eqilibrium which must be established between them. In general a rational application of these principles and these laws enables us to say, often even before making the experiment, why one given reaction is certain to result, while another reaction is impossible; why an action which begins without difficulty, ceases after a time; and finally why a particular phenomenon occurring under certain circumstances, does not take place under other circumstances entirely similar apparently in appearance." The introductory portions of the book are therefore devoted to calorimetry and the general principles of Thermo-chemistry as laid down by Berthelot. In the First part, a general study of the metals is given, covering about four hundred pages. It includes the principles of metallurgy, the physical properties of the metals and their alloys, their compounds with the non-metals, the action of water, acids, etc., on the metals, and lastly metallic salts. The Second part is devoted to the study of the metals specially. Throughout the book all the reactions are given as energy-reactions, and represent the heat-changes concerned, thus :

$$SnCl_2 + 2HO = SnO_2 + 2HCl_{diss.} + [67{\cdot}9 + 2.39{\cdot}3 - 64{\cdot}6 - 2.34{\cdot}5] \; [+ 12{\cdot}9].$$

The notation used in the book is the old equivalent notation; which seems unfortunate since it is not in accord with that based on the atomic theory now generally employed. The great advantage of considering the heat-changes in all reactions, and the evident care with which the descriptive part has been written, will make Professor Ditte's book acceptable to the chemist. We shall look with interest for the remaining parts. G. F. B.

II. Geology and Natural History.

1. *Composition of the Till or Bowlder-Clay;* by W. G. Crosby (Proc. Bost. Soc. Nat. Hist., xxv, 1890).—In this paper Professor Crosby gives the results of an investigation of the glacial deposits in the vicinity of Boston. His analyses show that the proportion of true clay in the till is small and that of rock-flour, or very finely pulverized rock, is large. He concludes that the proportion of stones over two inches in diameter is not over 5 to 10 per cent. His results give for the gravel, 24·90 per cent; the sand, 19·51; the rock-flour, 43·86; the clay, 11·67 = 99·94. In his table, each of these divisions of the material, is farther subdivided into coarse, medium and fine. Moreover, he gives his results for each of the different localities studied. In the redistribution of the material by the glacial flood, the rock-flour goes with the clay, adding to its volume, so that the clay-beds embrace fully half of the original material of the till. The rock-flour was found to be essentially quartz-flour—this being the final result of disintegration and the consequent decomposition—according with Daubrée's observation that the milky turbidity of the Rhine, even for hundreds of miles from the Alpine glaciers, is due chiefly to impalpable quartz. It is further concluded that of the material of the till, one-third is probably of preglacial erosion, and two-thirds of glacial erosion. The amount of rock-flour is evidence in favor of this. But the fact does not, Professor Crosby observes, lend support to the view that the glacier "profoundly modified the topography of the glaciated area." These are a few of the important facts and conclusions in Professor Crosby's excellent paper.

2. *Geology of the Rocky Mountain Region in Canada with special reference to changes in Elevation and to the History of the Glacial Period;* by Dr. G. M. Dawson.—The eighth volume of the Transactions of the Royal Society of Canada, contains, among its papers, the very valuable Presidential Address of Dr. G. M. Dawson on the above subject. The Mesozoic and Tertiary history occupies 22 pages, and the Glacial history the following 50 pages.

3. *The Greenstone Schist areas of the Menominee and Marquette regions of Michigan;* by Professor G. H. Williams. 218 pp. 8vo, with plates and cuts. Bulletin U. S. Geol. Survey, No. 62.—The important subject here discussed ably and with great fulness, by the author is—the Methods in which a massive crys-

talline rock may be modified by the action of orographic forces. The three methods mentioned—the Macro-structural, Micro-structural and Mineralogical, are severally considered, and the results under each, as recognized by the author, are described in detail, and illustrated by his microscopic study of the Greenstone schist and the associated rocks.

4. *Some Botanic Gardens in the Equatorial Belt and in the South Seas.* (Second paper.)—The voyage from Colombo, Ceylon, to Adelaide, South Australia, is not far from 4,400 miles, After leaving the harbor, land covered with tropical vegetation and shores fringed with mangrove are kept in sight, until the once prominent port at Point de Galle sinks from view, and then a fairly straight run is made for Cape Leeuwin. Rounding this, the distant shores of West Australia are skirted as far as the Head near King George's Sound, at Albany, after which no land is seen until Kangaroo Island is reached about the fourteenth day out. The landing is made in a steam launch which runs in all weathers, sometimes in pretty rough water, through an open roadstead, up to a jetty at the Semaphore, the terminus of a suburban railway leading to the City of Adelaide. Passengers by the Peninsular and Oriental line land at Glenelg, a little farther south.

The clouds of grasshoppers which met us at the landing did not presage a very happy condition of things in the fields and gardens. But the mischief thus far wrought by them had been local and hardly so severe as had been dreaded. It was now the middle of December (the southern summer) and the ground seemed dry, but the crops around the city were in good color and strong.

For a comparatively new city, Adelaide is fairly well shaded with trees. The suburbs are attractive. Northeast of the city proper, and within a few minutes walk from the principal streets, the University and the Botanic Garden are found near together.

Adelaide.—The Botanic Garden occupies an area of about forty acres, and adjoins parklands which are used as an arboretum. From his entrance at the main gate, throughout his whole tour of the garden, the visitor is struck by the more or less successful attempts at decorative management of shrubbery and marble statuary, indicating that there has been a desire to make a place which is easily accessible very attractive to the public. The result is generally pleasing; in fact, it is all good, except in the case of the water, which leaves much to be desired.

Australian plants are represented by pretty good specimens, but the conditions for culture are not favorable. The soil appeared thirsty and for the most part light; hence the fair success attained shows excellent judgment in cultivating. As will be seen by the photographs at Cambridge, the large specimen trees would be a credit to any garden, and the groups of European florist-plants are about as good as one could expect to see anywhere. It was said to me that these European groups are among

the main attractions of the garden to the citizens. The citizens with whom I conversed were justly proud of the establishment.

The Victoria regia house is one of the principal features of the garden, but the condition of the plants at the time of my visit was a disappointment. It seemed as if the method of heating by water from an open boiler might be at fault. It was not easy to see how the water could contain as much air as in the ordinary method of heating by pipes through the tank, and it appeared as if this was at the bottom of the mischief.

The other houses looked well for the season. The selections in them appeared judicious and many individual plants were of exceptionally good growth. Considerable prominence was given to horticultural, and, one may say, utilitarian aspects of vegetation. This doubtless serves to augment the interest felt by the general public, from whom directly or indirectly all the funds come.

A Museum for economic botany, well-arranged, and full of good illustrations of the subject, occupies a conspicuous place in the grounds. Its most attractive department is a collection of the leguminous plants which have proved pernicious to stock. The carpological series is good, and the products of the useful plants are well displayed. In a separate apartment was seen the herbarium of the director, Dr. R. Schomburgh, who was even then prostrated by illness which has since terminated fatally.

Although confined to his room and a great sufferer, the venerable Director received me on two occasions and conversed freely about his plans, all of which looked in the direction of increasing the local interest in Botany and Horticulture.

Very profitable botanical excursions can be made from Adelaide. The hand-book for the neighborhood is a recent Flora by Professor Tate of the University. It is handy and accurate. Visitors who may have time for botanical studies in any of the Australasian colonies should be reminded that in almost every large city there can be found a botanist or two well acquainted with the most desirable localities for herborizing. Judging from my own experience in obtaining their advice, these local botanists are not easily wearied in well-doing. Some of the local collections are enriched by notes taken on the spot, and possess great interest.

Melbourne.—It was my good fortune to make the journey from Adelaide through Ballaarat to Melbourne in company with Mr. Samuel Dixon, of South Australia, who has acquired an excellent knowledge of the flora, and has occupied himself with some of the more interesting industrial questions connected with the forage plants of the Colonies. The first and last part of this railway journey of about 500 miles was made in the afternoon and early morning, and gave a glimpse of high lands and of the dreary desert scrub, with here and there a view of good soil and rich growth.

In passing, it may be noted that the railway journey northeast from Adelaide to the famous silver mines at Broken Hill in New South Wales brings before the tourist capital illustrations of true Australian deserts. In fact, the town of Broken Hill lies within sight of one of the spots where the great explorer Sturt was imprisoned by the lack of water. The scanty vegetation furnishes, as so many Australian plants elsewhere do, striking instances of adaptation to a dry climate; the locality is so readily accessible that it should not be left unvisited. Mr. Dixon gave many facts relative to the utilization of deserts and of desert plants in that region, which he has incorporated in an instructive article published in the Proceedings of the Royal Society of South Australia (vol. viii).

I had also the benefit of Mr. Dixon's guidance, the following day, in my first informal visit to the Botanic Garden of Melbourne. The garden is about a mile south of the city itself, and lies on the narrow river, the Yarra, which flows through Melbourne. The situation is good, but the soil in some parts is far from the best. The Australian flora is represented by fine old specimens, if one can call anything old in such a new country, and by young plants which have been added in recent years.

The garden abounds in effective views which are much appreciated by the citizens. As in all new countries, for instance, our own, there is a good deal of pleasant rivalry between the larger places; in the botanical gardens of Australia there is found a convenient object for comparison. The judicious visitor cannot go far wrong in his answers to anxious inquiries as to respective excellences of the gardens, where there is so much to please and so little that calls for unfavorable criticism.

In the Melbourne Garden the most attractive groups of plants are (1) the Proteaceous, composing a striking mass of shrubs and small trees many of which happened to be in flower: (2) the Eucalypts, by no means all of them equally good as representatives, but most of them having distinctive characters recognizable as a whole; (8) the Myrtaceæ, and the Acacias.

The best photographs of the Melbourne garden are those which show the groups in question, and two in which the Governor's residence is seen in the distance. The Director is much embarrassed by the peculiar condition of the labor question in Australia. Somewhat similar difficulties arise wherever the one in charge cannot employ or dismiss the workmen for whose good work he is held responsible.

Mr. W. R. Guilfoyle, the Director, with his capable assistants, is organizing a Museum of Economic Botany, and bringing together other appliances for the illustration of botany.

Not very far from the Garden lives Baron Ferdinand von Mueller, Government Botanist. He is surrounded by his Herbarium and Library to which he has devoted his life and fortune. The correspondence which he carries on is incredibly voluminous, and it is understood to be conducted wholly with his own hand.

His Handbook of Victorian Plants is easy to use after one becomes accustomed to the dichotomous arrangement, and it is very helpful in the minuteness of its descriptions. The Baron has done hard work in economic botany as applied to Australia and in the endeavor to make the useful plants of the colonies better known in the Old World and in America. As everybody knows, such work is always a thankless and ungracious task, for the mistakes and failures in the introductions are likely to outnumber the successes. In everything concerning the advancement of the colonies, Baron Mueller has taken a hearty interest and is in every way identified with his adopted home.

Besides the incipient economic Museum at the Botanic Garden and the large collections under the charge of Baron Mueller there is an interesting botanical department connected with the Melbourne Museum. This is under the direction of Mr. J. Cosmo Newbery, and is now being re-arranged previous to its final disposition in the new Museum building. The specimens which illustrate the cereals and their products were nearly arranged at the time of my visit and indicated that the new system would be successful from an educational point of view.

The environs of Melbourne include many municipalities which are commonly counted in with Melbourne proper, when the city is compared with its sister cities. Passing outside the circle of associated communities, the botanist comes upon very instructive botanical ground. One does not have far to go by rail to stand before the giant specimens of Eucalyptus, and by boat to be in the presence of queer Australian plants, like Epacris and so on, growing wild.

Sydney.—The third great Australian Garden is in New South Wales, about six hundred miles from Melbourne, Victoria. For beauty of situation it stands without a rival. It has a commanding position on the shore of the harbor, and possesses remarkable elements for landscape treatment.

The harbor of Sydney (Port Jackson) is one of the most celebrated in the world, usually being associated with that of Rio de Janeiro, as the finest in existence. Like outstretched divergent fingers, promontories extend into this charming sheet of water. On parts of the slopes of two of these the Botanic Gardens, covering about forty acres, have been established. As was to be expected, the representation of native plants is somewhat different from that in the other gardens, owing to difference in the climate. In certain directions, for instance, palms from the smaller islands of the Polynesian archipelago, the garden is exceptionally rich. The specimens are numerous and well grown. A good deal of attention has been paid also to economic plants. The most interesting photographs which I could secure were (1) Individual plants; (2) the Palms of Lord Howe's Island, etc.; (3) the general view from the brow of the hill. To Mr. Charles Moore, the director, I am indebted for many views of the garden, taken some time since. The collection of all these now at Cambridge

illustrates fairly well the wide range of cultivation possible in this favored climate.

Botany Bay of the early navigators lies within easy excursion distance of the city of Sydney. There and in the contiguous peninsulas, one can see growing wild the native plants which gave the place its appropriate name.

In point of fact, the garden at Sydney was visited considerably later by me than those at Adelaide and Melbourne, a journey through Tasmania and New Zealand intervening. But it has seemed best to bring the three larger gardens together in a single sketch, reserving the visit to the economic museum in Sydney for a third communication.

Before leaving the subject of these three gardens, it may not be out of place to call attention again to the deep interest and local pride felt by the people of the respective cities in these establishments. Every intelligent person with whom I conversed upon the subject appreciated the importance of such institutions in a country with undeveloped resources. It was also felt that, since these gardens, and the smaller ones, for that matter, keep in touch with Kew, the botanical interests of the colonies, particularly in their economic aspects, were receiving due attention.

The Botanic gardens of the south do not appear to sustain any close connection with the Universities. They are, of course, available for purposes of investigation, but they are governmental and not academic institutions.

It is frequently said that in the southern hemisphere everything is reversed from what is found in the northern. This is certainly not true of the budgets for botanical gardens. These institutions are everywhere very popular, but I did not find in any case that too much money was provided for the running expenses. In fact, I observed no instance where a somewhat larger income would not have improved the condition of affairs. But the directors and superintendents of the larger gardens, and the curators of the smaller ones made the best use of the rather scanty funds placed at their disposal.

The position of government botanist (in Victoria), filled by the distinguished von Mueller, seems at first anomalous. But when it appears that, as matter of fact, this position has left its incumbent far more free to elucidate botanical questions affecting all the colonies, than if he were burdened with administrative duties connected with the botanical garden in one colony, the establishing of the office has had happy results. It may not be out of place to say that on every hand in the colonies Baron von Mueller's preëminence receives hearty recognition, even in quarters where the relations might naturally have been somewhat strained. The willingness with which the government botanist comes to the assistance of young botanists and amateur collectors in the colonies may have had much to do with the general interest in botanical matters exhibited in the three most populous colonies. G. L. G.

APPENDIX.

Art. XXVI.—*Notice of New Vertebrate Fossils;* by O. C. Marsh.

Recent researches on a number of extinct animals have made it evident that several of them are new to science, and that others possess some characters of interest which have not hitherto been observed. In the present paper, some of the results of this investigation are placed on record, and others will be given in a later communication.

CERATOPSIDÆ.

Triceratops elatus, sp. nov.

One of the largest members of the *Ceratopsidæ*, representing a distinct species, is at present known from the skull only, which was secured during the past year. Although this skull is about six feet and a half in length, it belonged to an animal scarcely adult, as indicated by some of the cranial sutures. The rostral bone is not coössified with the premaxillaries as in old animals, and the superior branch of the former bone has its extremity free. The nasal horn-core, however, is firmly coössified with the nasals. It is of moderate size, with an obtuse summit directed upwards. The main horn-cores were quite long, with their extremities pointed and directed well forward. These horn-cores are compressed transversely, the section being oval in outline.

One of the most striking features of the skull is the parietal crest, which was quite elongate, and much elevated, more so than in any of the species hitherto discovered, and this has suggested the specific name.

The length of this skull from the front of the rostral bone to the back of the parietal crest was about seventy-eight inches, and the greatest transverse expanse of the posterior crest was about forty inches. The summit of one of the frontal horn-cores was about twenty-eight inches above the orbit, and fifty-three inches from the base of the quadrate.

This interesting specimen was found in the Ceratops beds of the Laramie, in Wyoming, by Mr. J. B. Hatcher of the U. S. Geological Survey, whose previous discoveries are well-known.

Torosaurus latus, gen. et sp. nov.

Another well-marked species of this group, which may be referred to a new genus, is represented by one skull, and parts of the skeleton, from nearly the same horizon as the specimen above described. One of the most striking features of the present species is seen in the posterior crest, which, instead of being complete as in the skulls hitherto found, is perforated by a pair of large openings. These are in the parietals, but they have the inner margin of each squamosal for their outer border. They are well behind the supra-temporal fossæ, but doubtless were originally connected with them. They may be called the supra-temporal fontanelles. The squamosal bones, moreover, are very long and slender, and distally only show near the ends sutures for union with the parietals. Another distinctive character is seen in the main horn-cores, which are placed well back of the orbit. The nasal horn-core is short, with the apex compressed, and directed forward.

This genus is of much interest, as it represents an earlier and less specialized form than either *Ceratops* or *Triceratops*, both of which have the posterior crest complete. The existing Chameleons show the other extreme, where the outline only of the parietal crest has been attained.

Some of the principal dimensions of this skull are as follows:

Length from apex of nasal horn-core to extremity of squamosal	80	inches.
Distance from same apex to front of orbit	21	"
Distance from same to front of parietal opening	54	"
Width between posterior extremities of squamosals	56	"

This important specimen was discovered by Mr. J. B. Hatcher, in the Laramie of Wyoming.

Torosaurus gladius, sp. nov.

A second species of apparently the same genus is represented by various portions of a skull in good preservation. In this specimen, the nasal horn-core is short and obtuse, and nearly upright. The main horn-cores are elongate, oval in outline, and in position resemble those of the skull above described. The most remarkable features in the present specimen are the squamosal bones, which are greatly elongated, and so attenuated as to have the general shape of the blade of a sword, thus suggesting the specific name. These bones, moreover, show but slight evidence at their distal extremity of union with the parietals, as the inner margin is rounded for nearly half the length. This feature will distinguish the present species from all others hitherto described.

The following are some dimensions of portions of this specimen:

Length of horn-core from top of orbit to summit	27	inches.
Antero-posterior diameter of same horn-core at base	8	"
Transverse diameter of same	5	"
Length of squamosal behind exoccipital groove	55	"
Greatest width	15	"
Width at middle	9	"

These interesting specimens were also found in the Laramie of Wyoming by Mr. J. B. Hatcher.

ANCHISAURIDÆ.

Ammosaurus, gen. nov.

The Yale Museum has recently secured two interesting specimens of Dinosaurs from the Triassic sandstone of the Connecticut valley. In comparing these with the known species of *Anchisaurus* from this formation, the fact became evident that among them are two well-marked genera. One of the specimens, which is described below, cannot now be distinguished generically from the type of *Anchisaurus*, while the one described by the writer as *Anchisaurus major* is quite distinct, and hence a new genus is here established for its reception. The distinctive characters are well marked in the pelvic arch.

There are three vertebræ in the sacrum, but they are not coössified with each other, being free, as in the *Crocodilia*. The ilium is comparatively small, and has a slender pre-acetabular process. The pubes are broad, elongate plates, perforate above, and not coössified with each other. In form, they resemble the corresponding bones in *Zanclodon*, where, however, the two are coössified, and imperforate. The ischia meet the pubes by an extensive union. Their distal ends are slender, directed backward, and closely adapted to each other. This species may now be known as *Ammosaurus major*.

Anchisaurus colurus, sp. nov.

The new species is represented by perhaps the most perfect Triassic Dinosaur yet discovered, as the skull and greater portion of the skeleton were found in place, and in fine preservation. It is smaller than the specimen above described, but similar in its general proportions, yet the two may be readily distinguished by the pelvic arch and posterior limbs. The pubes are distinct from each other, imperforate above, and the distal portions are only moderately expanded. The process that projects backward to meet the ischium is slender, and the face for union with that bone is quite small. The sacrum and ischia resemble those of *Ammosaurus* above described.

The skull is of moderate size, and of delicate structure. In its general shape, it somewhat resembles the skull of *Hatteria*. The supra-temporal fossæ are very large, and the orbits especially so. The quadrate is inclined forward, and the upper and lower temporal arches are slender. Compressed, cutting teeth are present both in the premaxillary and maxillary bones. The lower jaws have similar teeth, and the rami are not united to each other at the symphysis in front.

The vertebræ and limb bones are hollow, and the whole skeleton is lightly built. The neck is long, and the tail of moderate length. The scapula is elongate, and the coracoid very small and imperforate. The humerus has a strong radial crest, and the radius and ulna are nearly equal in size. There were five digits in the manus, the first, second, and third being armed with strong claws.

The femur is longer than the tibia, and has a flattened head, somewhat like that of a crocodile. The tibia is short and stout, and the fibula well developed. The astragalus is not coössified with the tibia, and the calcaneum is distinct. There were five digits in the pes, but only four functional, the fifth being represented by the metatarsal alone.

The skull of this reptile is about five and one-half inches long, and the lower jaw four and one-half inches. The scapula and humerus are of equal length, each about six inches long. The femur is about eight inches in length, and the tibia about six. The animal when alive was about five and one-half feet long. The present remains were found near Manchester, Conn.

A more complete description of this interesting reptile, with illustrations, will soon be published.

BRONTOTHERIDÆ.

Allops crassicornis, sp. nov.

The present species is represented by the nearly perfect skull of an adult, but not old animal. The skull is of medium size, with the zygomatic arches moderately expanded. The nasal bones do not project beyond the premaxillaries. The horn-cores are very short and massive, with rounded summits, and thus form one of the striking features of the skull. The dentition is complete, and in fine preservation. The single incisor is quite small, and situated close to the canine. The latter is of moderate size, and projects but little above the rest of the dental series. There is no diastema between the canine and the first premolar, which is small, and has its inner face on a line between the canine and the second premolar. The second, third, and fourth premolars are large, and have a strong inner basal ridge. The last molar has its anterior margin somewhat in advance of the front border of the posterior nares.

The length of this skull on the median line is about thirty inches, and the width across the zygomatic arches twenty-three inches. The width across the horn-cores is fourteen inches. The extent of the superior dental series is sixteen inches.

The type of this species was found in the Brontotherium beds of South Dakota, by Mr. J. B. Hatcher.

Brontops validus, sp. nov.

This well-marked species is based upon a skull in fine preservation, which agrees in its main characters with the other species of this genus, but is particularly short and robust. The zygomatic arches are widely expanded, almost as much as in any skull of this group. The nasal bones have only a moderate extension in front, and do not reach the end of the premaxillaries. The free portion is broad and massive. The horn-cores are of moderate size, nearly round in section, and have their obtuse summits directed somewhat backward. The occipital crest slopes forward, and is expanded transversely. The length of this skull on the median line is about twenty-six inches. The greatest transverse diameter across the zygomatic arches is twenty-two inches, and across the summits of the horn-cores, fourteen inches.

The type specimen of the present species is from the Brontotherium beds of South Dakota, where it was secured by Mr. J. B. Hatcher.

Titanops medius, sp. nov.

The present species is from nearly the same horizon as the type of the genus, but is of smaller size. It is represented by one skull in fair preservation, with the horn-cores and dentition complete. The free portion of the nasals is very small, and projects but slightly beyond the anterior line of the horn-cores. The latter are compressed antero-posteriorly, and project laterally nearly at right angles to the median line of the skull. The two incisors on each side are quite small, and separated from each other and from the canine. There is a slight diastema behind the canine. The first premolar is small, and triangular in outline. The second premolar is of moderate size, and the third and fourth premolars have only an incomplete inner basal ridge.

The width of this skull across the horn cores is twenty-three inches, and the distance from the end of the nasals to the front of the posterior nares is sixteen inches. The extent of the upper dental series is seventeen inches. This specimen is from near the top of the Brontotherium beds of South Dakota, where it was discovered by Mr. J. B. Hatcher.

New Haven, Conn., August 10th, 1891.

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